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A DICTIONARY OF METALLOGRAPHY

A DICTIONARY OF METALLOGRAPHY

By

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PREFACE

ORIGINALLY, and in its more restricted sense, Metallurgy denoted the art of extracting metals from their ores, together with such refining as was necessary to make them suitable for industrial use. The use of the term has gradually been extended, however, to cover not only a great many further processes and treatments applied to metals and alloys after their extraction and refining; but also the whole field of study of their constitutions, internal structures, physical properties and behaviour in service. It has thus become customary to distinguish between Chemical Metallurgy, comprising reduction and refining; and Physical Metallurgy, comprising the study of those other matters detailed above.

There seems also to be no real distinction between Physical Metallurgy and Metallography, for, according to the Standard Definitions E7—27 of the American Society for Testing Materials, Metallography denotes that branch of science which relates to the constitution and structure, and their relation to the properties of metals and alloys. Again, Desch's well-known textbook on the subject is entitled *Metallography*, a similar usage being also employed by other writers; and, since "Physical Metallurgy" is a somewhat cumbrous designation, "Metallography" has been adopted as the name for this science in the present work.

It is of course a comparatively young science, which affords some explanation for the fact that there is—so far as the author can ascertain—no comprehensive dictionary of its terms. Greenwood's excellent *Glossary of Metallographic Terms*, published in Australia, covers only 188 terms. One may also find short selected lists of definitions in various textbooks. The authors of these, even the best of them, have a habit of writing all about a term without actually defining it—a method which does not really "crystallize" the term in the mind of the reader.

Again, the British Standards Institution, the American Society for Testing Materials, and other bodies, define a very limited number of terms in their specifications; as also do the authors of some technical papers, but even these have to be searched for, and are usually not available when required. A dictionary of metallographic terms appears, therefore, to be needed very badly; and it is hoped that this deficiency will be supplied in some measure by the present work.

In order to keep it within reasonable dimensions, chemical metallurgy has not been specifically dealt with, metalliferous minerals and mining terms having thus been excluded. Since, however, variations in smelting and refining procedure often lead to cor-

responding differences in mechanical and physical properties, this section has been covered to a very limited extent, as with the terms relating to the manufacture of iron and steel.

As to the scope of the work in general, while it is quite easy to decide upon the terms it is essential to include, it is much more difficult to know what to leave out. Metallography obviously includes micrography, macrography, radiography, mechanical and magnetic testing and the like. It further embraces a good deal of chemistry, physics and physical chemistry—sciences which now have boundaries so ill-defined that it is difficult to say where one leaves off and another begins. But it was obviously impossible to cover completely all of these collateral sciences without making the work of quite inordinate dimensions. It has been therefore necessary to exclude most chemical, physical, electrical and magnetic terms, and these can already be found in dictionaries devoted to these sciences. But electricity plays so fundamental a part in metallography—as in atomic structure, electro-deposition and corrosion phenomena generally—that *some* electrical terms had necessarily to be included.

It thus became essential to use much discrimination in selection, introducing the inevitable difficulty that even expert individual opinion must vary greatly as to the terms that should, or should not, be included. It is hoped, therefore, that some toleration will be exercised in this matter. It may be assumed that sufficient evidence could be adduced for the inclusion of any term which has been inserted. It would also be presumptuous to claim that there are no important omissions, which it is hoped to include in a subsequent edition.

The field which it has been endeavoured to cover will already be sufficiently obvious, but it may be useful to indicate some deliberate omissions and the reasons therefore. Thus, while the individual metals and a few of the main groups of alloys have been dealt with, it has for reasons of time and space been impossible to cover the legion of proprietary alloys, which are also covered to some extent by existing lists. Again, although definitions of a limited number of terms used in welding are naturally given, it was clearly impracticable to attempt to include many others; particularly, for example, the many different types of welded joint; where, apart from their number, it is often almost impossible to devise a satisfactory definition without an illustration. In certain other cases, a figure would naturally have often been helpful, although not absolutely essential.

There is also the question of indexing. There are many terms described in two or more words, as "Blue Brittleness", "Temper Brittleness", etc., which might be classified either under the initial letter of the first word, because that is how one usually thinks of the

term ; or, alternatively, under the initial letter of the second, because it is the more significant ; in that " blue " and " temper " refer merely to different kinds of brittleness. Here, however, the awkwardness of the second method has led to its abandonment in most cases. A departure from this rule has been made, however, for the various welding processes, on the ground that, if these were kept together under " Welding ", comparison would be quicker and more convenient.

It would be impracticable to list all the sources consulted during the three years or so in which the work has been in progress. A certain number of official definitions have been taken from the specifications of the American Society for Testing Materials, the American Society for Metals, the British Standards Institution and other Societies, and this assistance is gratefully acknowledged. The author must also express his indebtedness to his friend and colleague, Mr. J. R. Bryant, B.Sc., for kindly reading the MSS. and making a number of valuable criticisms and suggestions.

R. T. R.

BEDFORD,

October, 1944.

ABBREVIATIONS USED IN THE TEXT

| | |
|----------------------|--|
| A.S.M. . . . | American Society for Metals. |
| A.S.T.M. . . | American Society for Testing Materials. |
| A.W. | Atomic Weight. |
| At. No. . . . | Atomic Number. |
| B.S.S. | British Standard Specification. |
| B.Th.U. . . . | British Thermal Unit. |
| <i>c.</i> | (<i>circa</i>) about. |
| c.c. | cubic centimetre. |
| c.g.s. | centimetre gram second (metric scale units). |
| <i>Cf.</i> | Compare. |
| cm. | centimetre. |
| e.m.u. | The electromagnetic c.g.s. unit— $10\cdot0000$ coulombs (absolute) ; $2\cdot99796 \times 10^{10}$ e.s.u. |
| e.s.u. | The electrostatic c.g.s. unit— $3\cdot33560 \times 10^{-10}$ coulombs (absolute) ; $3\cdot33560 \times 10^{-11}$ e.m.u. ; $2\cdot0947 \times 10^9$ electronic charges. |
| El. | Element. |
| gm. | gram. |
| K. | Kelvin or Absolute Temperature Scale ($^{\circ}$ K. = $^{\circ}$ C. + 273·18). |
| kg. | kilogram. |
| M. Pt. | Melting Point. |
| mm. | millimetre. |
| mμ | millimicron, 0·001 micron ; 1×10^{-8} metre ; 10 Angstroms. |
| μ | micron, $3\cdot937 \times 10^{-8}$ in. ; 1×10^{-8} metre ; 1×10^4 Angstroms. |
| O.P.M. | U.S. Office of Production Management. |
| Prop. | Proposed. |
| q.v. | which see. |
| S.A.E. | Society of Automotive Engineers (U.S.A.). |
| S.G. | Specific Gravity. |
| Sp. H. | Specific Heat. |
| Std. Defn. . . | Standard Definition. |
| Std. Spec. . . | Standard Specification. |
| Stds. | Standards. |
| Tent. Std. . . | Tentative Standard. |
| w.-l. | wave-length. |

A

Abrasion. Wear by rubbing. The removal of particles of a material by sliding contact with some other material, generally one of considerably higher resistance to a. Oxidation plays a great part in a., *e.g.*, in rail tests made in a vacuum or inert gas, wear was no longer found, the surfaces merely becoming highly polished. The hardness value may be no criterion of a. resistance, which requires toughness, as well as strength and hardness.

Absolute Temperature. T. measured from the absolute zero, the t. at which all molecular motion ceases, *i.e.*, 0° Abs. = -273.18° C. or -457.72° F. To obtain a.t., these figures are added to the ordinary readings on the Centigrade or Fahrenheit scale, respectively.

Absorption. (1) The disappearance of a gas, liquid or solid by incorporation in another liquid or solid, so that the matter is taken up by the whole mass of the absorbing agent. The absorbed substance may retain or lose its separate existence. The a.-coefficient of a gas in a liquid is the volume of gas, reduced to 0° C., absorbed by 1 volume of the liquid at the experimental temperature. (2) For radiant energy falling upon a body, the process whereby some of this energy passes into the body and is converted into heat, instead of being reflected.

Absorption Spectrum. See S.

Absorptive Power (or Absorptivity). Of a non-black body, the fraction of the radiation falling upon the body which it absorbs in unit time, *i.e.*, the ratio of the radiation it absorbs to that absorbed, under the same conditions and in the same time, by a black body. This ratio varies with the type of surface and the w.-l. of the incident radiation. A.p. is equal numerically to emissive p. (q.v.).

Ac and Ar Points. Symbols representing transformation temperatures, or (since the rise or fall of temperature is momentarily retarded) arrest p., in the heating and cooling of irons and steels. There are nominally four, known as A_1 to A_4 . Depending upon composition, however, a particular p. may not be found; or two p. may merge into one, as shown below. There is, in high-carbon steels, an arrest p., known as A_{cm} (q.v.), not shown by low-carbon steels. P. on heating are known as Ac_1 , etc. (from the Fr. *arrêt*, arrest; and *chauffage*, heating). The equivalent p. on cooling are

D.M.

I

B

Acc

known as Ar_1 , etc. (Fr. *refroidissement*, cooling). Ar_1 , equivalent to Ac_1 , is the fourth, and not the first transformation on cooling. By reason of *thermal lag* (q.v.), the heating change p. is raised and that on cooling depressed, as compared with the mean temperature, which also varies with composition. Ac_1 represents the pearlite \rightarrow austenite transformation, and Ar_1 the reverse. It is not shown by pure iron. For a 0.20 per cent. carbon steel, Ac_1 is 730° and Ar_1 695° C. Ac_2 and Ar_2 do not denote a true transformation temperature, but only the magnetic change p. (or Curie p., q.v.). In pure iron, Ac_2 is 800° and Ar_2 780° C.; while, for a 0.20 per cent. carbon steel, they are 770° and 768° C., respectively. In pure iron, Ac_3 represents an allotropic change from α - to γ -iron, and Ar_3 the reverse change, at temperatures of 905° and 880° C., respectively. In low-carbon steel, Ac_3 is the *end* of a transformation (extending over a wide range of temperature, from about 700° to 900° C.) in which the last ferrite is converted into austenite; Ar_3 denoting the *start* of the same transformation, when ferrite begins to be deposited from austenite. For a 0.20 per cent. carbon steel, Ac_3 is 885° and Ar_3 860° C. With a higher carbon content, A_3 and A_2 gradually approach, until, with a content of about 0.30 per cent., the two merge into one, the p. being now known as $A_{3.2}$. With still higher carbon contents, $A_{3.2}$ and A_1 also approach and merge at a content of about 0.85 per cent., the point being now known as $A_{3.2.1}$, with the suffix *c* or *r*, respectively. A_4 denotes the change from γ - to δ -iron on heating and vice versa on cooling, this being discussed under *Delta Iron* (q.v.).

Accelerated Ageing. See **Artificial Ageing**.

Acicular. (1) Needle-shaped, e.g., the martensitic "grains" in quenched high-carbon steel; these, however, being actually cleavages of octahedra. (2) Sharp-pointed.

Acid. A compound which, in aqueous solution, gives rise to hydrogen ions; turns many blue vegetable colours (as litmus) red; reacts with an alkali to form a neutral salt, and is a solvent of many materials.

Acid Brittleness (or Pickling Brittleness). See **Pickling**.

Acid Steel. Steel made under a siliceous slag, having an "acid" reaction, in a furnace with an "acid" inner bottom and lining, i.e., one composed of white sand, siliceous rock or silica bricks, all of which are composed mainly of silica (SiO_2), the anhydrous form of silicic acid. A.s. is used for the more important duties, as ordnance/

materials, particularly gun forgings and projectiles, as well as large forgings requiring high transverse ductility.

A_{cm} Point. The symbol of a transformation, shown only by hyper-eutectoid steels, in which, at temperatures varying with the carbon content, free cementite begins to separate on cooling, and continues to do so until the residual austenite has reached eutectoid composition at $A_{s.s.1}$, when it is transformed to pearlite. With increase in carbon content from about 0.85 to 1.70 per cent., the A_{cm} point is raised from about 690° to 1130° C. ; but, in practice, it is not very evident in steels containing less than about 1.20 per cent. of carbon. The reverse effect is shown on heating.

Adherence. In magnetic testing, the property of a powder, either dry or in liquid suspension, which depends upon its magnetic permeability, and causes it to accumulate in a well-defined area above a crack or other defect.

Adsorption. The concentration of a gas, liquid or dissolved substance on the surface of a solid, the adsorbent, so that the gas pressure or the concentration of the solution diminishes. An example is the occlusion of gases by spongy metals. *A.* is due to the intermolecular forces existing at such a bounding surface. *A.* differs from *absorption*, in which the matter is taken up by the whole mass of the absorbing agent, instead of being concentrated on the surface, as in *a.* Adsorbed substances can be removed by heating, washing or exhaustion.

Ae_1 Point. For a steel of eutectoid composition, a characteristic equilibrium temperature above which the steel will remain indefinitely in the austenitic state ; and below which the austenite is unstable and tends to transform. When a steel previously rendered austenitic is held at a constant temperature below this limiting temperature, the transformation is not instantaneous, but requires, for its onset and for its completion, definite periods which are characteristic, for a given steel, of the temperature level at which the steel is being held. See *S-Curve*, *Split Transformation of Austenite*, etc.

Aero-Case Process. A case-hardening process using a liquid bath, in which the activating agent is calcium cyanide, added to a bath consisting of a mixture of anhydrous sodium and calcium chlorides. Here the case is similar to that obtained in the usual sodium cyanide liquid bath, but is somewhat higher in carbides and lower in nitrides.

Aft

Afterworking. See **Elastic Recovery.**

Age-Hardening. A type of hardening resulting from a process of ageing (q.v.). It is the result of a partial transformation of a super-saturated solid solution, when the excess phase tends to be precipitated, with a resultant increase in proof stress, ultimate stress and hardness values, and some reduction in ductility, as compared with the normal alloy. Ageing of solution-treated alloys, particularly aluminium alloys, is thus often employed industrially. It may consist simply of a period of standing at room temperature (natural ageing) ; or of a treatment at a higher temperature (artificial ageing). In the second case, the process is equivalent to tempering, and the effect is a variety of temper-hardening. The attendant structural transformations may be sub-microscopic, involving a change in the atomic lattice structure ; or may be attended by visible precipitation of the excess phase (shown by microscopic examination), an effect sometimes known as "precipitation hardening". In this case, the hardening effect is usually more pronounced, the lower the temperature at which the transformation can be effected, and therefore the finer the particles of the dispersed phase, an effect sometimes termed "dispersion hardening".

Ageing. The process of allowing a metal or alloy to remain at room temperature for a time sufficient to permit a particular structural transformation to be effected. It involves the partial recovery from an unstable condition produced either by quenching or cold work (whence the terms quench-ageing and strain-ageing). These two may also occur together, since cold work promotes the deposition of excess phase from a super-saturated solid solution. In general, the *effects* of a. are more properly described as age-hardening (q.v.).

Aggregate or Aggregation. A mass of metallic or other crystals, which may be produced during solidification, by reason of an allotropic change, or by the recrystallization of strained metal. An a. may be either homogeneous, all the crystals being of the same kind (as in yellow brass) ; or heterogeneous, where the crystals are of more than one kind (as in mild steel, showing crystals of ferrite and pearlite). In a homogeneous a., the crystals may be oriented uniformly, constituting a parallel growth (q.v.) ; or the orientation may vary quite irregularly throughout the mass, as when solidification begins from a large number of nuclei at much the same time. In heterogeneous a., crystal growth of the independent constituents may be quite unrelated and irregular ; or one may influence the other, when the two may have at least one face and one axis in common, these being termed regular growths.

Air-Hardening (or Self-Hardening) Steels. S. whose critical cooling rates (q.v.) are so slow that they become martensitic on cooling from A_{c_3} , either in free air or by means of an air blast. A sufficiently rapid cooling can be obtained only if the part does not exceed a certain size, which varies with its composition. Among a.-h. s. are those containing 3.75–4.50 per cent. nickel, 1.0–1.5 per cent. chromium, with or without 0.15–0.20 per cent. molybdenum, such s. being used for highly stressed parts, including gears. The process of a.-h. may be followed by tempering, with the usual modification of properties. High-speed tool s. (q.v.) are also commonly air-hardened.

Air Separation. In Powder Metallurgy, the classification of metal powders into particle size ranges by means of a controlled air stream (A.S.M. Defn.).

Aired Bar. A b. of cemented or blister steel which has been rendered defective by the presence of air in the converting pot.

Alkali Metals. The odd series of metals in Group I of the Periodic Table, comprising lithium, sodium, potassium, rubidium and caesium, the most electropositive m. known, this quality—as also the basicity of the hydroxides, the “alkalies”—increasing in the order given. They all decompose water, with the evolution of hydrogen, with violence increasing in the same order. The other properties show a similar gradation.

Alkaline Earth Metals. The even series of m. in Group II of the Periodic Table, from beryllium to radium. The term is applied particularly, however, to calcium, strontium and barium, all of which oxidize in air and decompose water, but less violently than the alkali m. The hydroxides have a decidedly alkaline reaction, and—with that of magnesium—were early described as a.e. The three m. show a close relationship and a marked gradation in properties from calcium to barium, the a.w., s.g. and chemical activity of the m., and the basicity of the hydroxides, increasing in the order given.

Alligator Cracks. (1) C. in the form of a fine network, as shown usually on clamp-hardened tool steels, case-hardened and nitrided parts, and due to using a grinding wheel which is too hard, too large a feed and consequently too great a pressure, or insufficient coolant. The cause is the undue local expansion, under temperature, of surface metal which is restrained by the comparatively cold and rigid metal which “backs it up”. The remedy is obvious. (2) In a crucible,

All

fine c., giving the outside the appearance of a skin, which may develop after some time in service.

Allotriomorphic Crystals. C. which have been prevented from assuming their regular geometrical external form, as by the interference of adjacent growing c.

Allotropy. A phenomenon shown by various elements, which may occur in two or more states, differing widely in crystallographic habit, density, colour, reactivity, etc., and each stable within certain limiting conditions of temperature and pressure. In solids, these differences depend upon a rearrangement of the atoms upon a new space lattice, a change often attended by a marked evolution or absorption of heat. Thus the element carbon has three allotropic varieties, diamond, graphite and amorphous carbon. Iron exists up to about 900°C. as α -iron, having a body-centred cubic lattice; between 900° and 1400°C. as γ -iron, having a face-centred cubic lattice; while above 1400°C. and up to the melting point of 1537°C. , it exists as δ -iron, having, as α -iron, a body-centred cubic lattice. On heating the metal through the transformation temperature, the structure becomes completely recrystallized, a circumstance enabling the refinement of grain size by heat treatment. Among other elements showing allotropy are sulphur, phosphorus, tin, antimony, arsenic, nickel, cobalt and silver.

Alloy. A substance, having metallic properties, consisting of two or more metallic elements, or of metallic and non-metallic elements, which are miscible with each other when molten, and have not separated into distinct layers when solid. A. when solid may be composed of eutectics, eutectoids, solid solutions, chemical compounds, or of aggregates of these components with each other or with pure metals. In the commercial sense, the term "alloy" would also include the case where some separation into distinct layers had occurred (A.S.T.M. Std. Defn. E7—27).

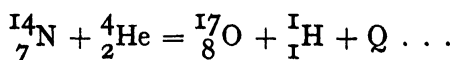
Alloy Phase. See Phase.

Alloy Steel. Steel possessing distinctive properties depending upon the presence of some element or elements other than carbon, or jointly on the presence of such elements and carbon. Nickel, chromium, tungsten, etc., make the steel more suitable for the performance of particular duties. By the American O.P.M., alloy steel is steel containing one or more of the following elements in excess of the proportion specified: manganese, 1.65 per cent.; silicon, 0.60 per cent.; copper, 0.60 per cent.; aluminium, chromium, cobalt, columbium, molybdenum, nickel, titanium,

tungsten, vanadium, zirconium, or any other alloying element in any amount specified or known to have been added to obtain a desired alloying effect.

Alpha Iron (or Ferrite, q.v.). The allotropic variety of iron stable below A_3 , at about 900°C ., crystallizing in the body-centred cubic form, almost incapable of dissolving carbon and strongly magnetic below about 780°C . α -iron may contain silicon or other elements in solid solution, when it has still the same structure as pure iron, and is still regarded as ferrite.

Alpha Particle, Symbol α or ${}^4_2\text{He}$. The helium nucleus, a sub-unit in nuclear structure, consisting of two neutrons and two protons, and therefore positively charged. The relative mass of an α p. where $O^{16} = 16$ is 4.003, its actual mass being 6.60×10^{-24} gm. and its radius 5×10^{-13} cm. An α -p. is emitted spontaneously from the nuclei of certain heavy radioactive elements, such as thorium and uranium, during their natural disintegration. The emission velocity varies with the element and may exceed 12,000 miles per second. The emission from an atom of an α p., involving the loss of two positive charges, in general removes the element two places in the Periodic Table in the direction of diminishing mass. Thus radium, with an at. no. of 88, contains 88 protons in the nucleus. Its disintegration, with the expulsion of an α p. containing two protons, leaves a nucleus with 86 protons, *i.e.*, that of a new element, niton, or radium emanation, of at. no. 86. The α p. has a positive charge of 9.54×10^{-10} e.s.u. or 3.18×10^{-20} e.m.u., twice that of the proton, and thus the repulsive force between it and the positively charged nucleus makes it proportionately less penetrative for the same kinetic energy. Being also a tightly packed structure, with little internal energy available for disintegration, it is a less effective projectile for atomic bombardment than the proton. Under suitable conditions, however, an α p. can be made to enter into the structure of a number of lighter elements; from which, in general, a proton is released in consequence. Thus, nitrogen is disintegrated by α p., to give oxygen of mass no. 17, as follows:



"Altered" Metal. The thin surface film of amorphous metal produced by the polishing of a metallographic specimen.

• **Aluminium.** Al. El. A.W. 26.97; At. No. 13; S.G. 2.69; M. Pt. 660°C . Soft, light silvery-white metal, malleable and ductile, and

Alu

a good conductor of electricity. Occurs in many forms. Produced almost entirely from *bauxite* ($\text{Al}_2\text{O}_3 \cdot 2\text{H}_2\text{O}$). This is purified by a complex process to produce alumina, which is dissolved in molten cryolite ($\text{AlF}_3 : 3\text{NaF}$) and electrolysed in a rectangular iron box, the cathode; while the anodes are carbon rods. The liquid metal falls to the bottom of the box, from which it is tapped at intervals. A. and its legion of alloys are used for structural purposes in aircraft, etc. The metal is used for electrical purposes (overhead transmission lines, busbars and so forth), cooking utensils and many other purposes.

"Aluminium Bronzes." (1) Straight aluminium-copper alloys containing no tin and usually from 7 to 10 per cent. of aluminium. They are characterized by a golden colour, a high corrosion resistance, excellent forging and rolling properties, and a strength and ductility in the worked state approaching that of mild steel. They are difficult to cast, any turbulence of flow tending to give rise to inclusions of alumina, with consequent embrittlement. There may also be pronounced piping (q.v.). Slowly cooled castings are liable to *self-annealing* (q.v.), which can be corrected by heat-treatment. (2) Alloys of higher strength, obtained by the addition of iron up to 5.5 per cent.—which can suppress self-annealing even in heavy castings produced under normal conditions—with sometimes manganese or nickel in addition, added at the expense of the copper. A well-known alloy containing 5 each of nickel and iron, 10 of aluminium and 80 per cent. of copper, shows in the cast state a tensile strength of 42–45 tons per sq. in., with 15–20 per cent. elongation; while even higher figures can be obtained by forging, rolling or extrusion.

Aluminizing. A heat-resistant aluminium-iron alloy coating produced on mild steels by metal-spraying the surface with aluminium, coating with bitumastic paint to prevent oxidation and heating to 780°C .

Aluminothermic Process. See **Thermit P.**

Amalgam. An alloy containing mercury, usually obtained by dissolving the second metal, *e.g.*, copper, silver, lead, gold, etc., in mercury.

Amorphous (or Vitreous). Non-crystalline, characterizing the thin layer of altered metal on the surfaces of polished metallographic specimens, produced at slip surfaces, etc. In the a. condition, the crystal structure of the metal has completely broken down, the molecules being distributed quite irregularly, as in the liquid state.

The a. film may thus be regarded as undercooled liquid metal, and there is considerable experimental evidence to support this view.

Analysis, Thermal. See Thermal Analysis.

Angstrom or Ångström Unit, Symbol Å or A.U. A unit used to express w.-l., employed in spectroscopy, for X-rays and γ -rays, in radiometry, colorimetry and radio communication. The a. is 10^{-10} metre, 3.937×10^{-9} in., $\frac{1}{10,000}$ micron, having been defined (1907) so that the w.-l. of the cadmium red line at 15°C. and 760 mm. pressure is 6438.4696 international Å.

Anion. In an electrolytic cell, a negatively-charged ion (q.v.) which travels towards the anode, and is there liberated, with appropriate chemical action.

Anisotropic. Of materials having different properties in different directions, examples being single crystals and worked metals.

Annealing. A heating and cooling operation of a material in the solid state. A. usually implies a relatively slow cooling. A. is a comprehensive term. The purpose of such a heat treatment may be: (a) to remove stresses; (b) to induce softness; (c) to alter ductility, toughness, electrical, magnetic or other physical properties; (d) to refine the crystalline structure; (e) to remove gases; (f) to produce a definite microstructure (Joint Cttee. of A.S.T.M., S.A.E. and A.S.M.). In a., the temperature of the operation and the rate of cooling depend upon the material being treated and the purpose of the treatment. A. differs from tempering, in that it may be applied to steel which has not previously been specifically hardened.

Anode. The positive electrode in an electrolytic cell; the electrode through which a direct current enters the liquid.

Anodizing (Anodic Oxidation or A. Treatment). A process, applied to aluminium and its alloys, in which the part is made the anode in an electrolytic cell containing dilute chromic, sulphuric or oxalic acid; the cathode, varying with the electrolyte, being of lead, iron or carbon. The operating conditions vary with the process, but in all cases oxygen is generated at the anode and attacks the aluminium, giving rise to a thin tenacious corrosion-resistant film, which may be thickened up to $\frac{1}{1000}$ in. if desired. The film is somewhat porous, and it is usually "sealed" by means of lanoline dissolved in petrol. If required, the anodized surface can be coloured with various aniline dyes before sealing.

Ant

Antimony. Sb. El. A.W. 121.76; At. No. 51; S.G. 6.67; M.Pt. 630° C. Lustrous white metal with a bluish tinge and crystalline (rhombohedral) structure. Very brittle and readily powdered. A poor conductor of heat and electricity. Expands slightly on solidifying. Found free in small quantities but occurs chiefly as *stibnite* (Sb_2S_3), which is reduced in crucibles in a reverberatory furnace by the addition of wrought-iron scrap, with common salt, to promote slag formation and separation of impurities and reduce volatilization. The resultant *singles* (92 per cent. Sb) are re-treated with salt and more stibnite to produce *star bowls* (99.6 per cent. Sb), which are further treated to produce *star antimony*, having a fern-leaf or star structure, characteristic of metal of high purity. In an alternative method, the oxide, obtained by a method of volatilizing roasting, is reduced by carbon in the presence of alkaline fluxes. A. is used in bearing alloys, type metal, battery plates, bullets and for many other purposes.

Aphonia. A term applied by Robin (Iron & Steel Institute, *Carnegie Scholarship Memoirs*, 1910, vol. 2, p. 1), in investigating the influence of temperature upon the acoustical properties of steel, to the refusal, of soft iron when suspended and struck at a temperature of 120° C., to ring in the usual manner. This "sound decay" is apparently closely analogous to the damping of a mechanical vibration (see **Damping Capacity**).

Arborescent. See **Dendritic**.

Armco Iron. See **Ingot I**.

Armour Plate. Heavy steel plate used as a protective sheathing for warships, tanks, etc. The nickel, nickel-chromium or other alloy steel employed in either deeply carburized, up to a depth of perhaps 1 in., and heat-treated to produce an extremely hard surface layer (surface-hardened type); or is hardened throughout the entire thickness (homogeneous type). The surface-hardened type is used primarily in parts subjected to the punching action of high-velocity shell. The homogeneous type is employed where, in addition to resisting penetration, deformation of the structure from heavy gunfire must be prevented.

Arrest Points. See **Ac** and **Ar P**.

Arsenic. As. El. A.W. 74.91; At. No. 33. Usual and stable form a steel-grey brittle crystalline metalloid, of s.g. 5.73, a fairly good conductor of heat and electricity. Two other allotropic forms, yellow (s.g. 3.7) and black (s.g. 4.7). Occurs free and as *realgar*

(As_2S_3), *orpiment* (As_2S_3), *arsenolite* or *white arsenic* (As_2O_3), combined with various metals as mixed sulphides and arsenides (e.g., *arsenical pyrites* or *mispickel*, FeSAs) and in other forms. Obtained by reducing the oxide with carbon or by heating mispickel with iron, when the a. sublimes into an inverted iron cone placed over the crucible. Used as a hardener in lead for bullets, as a bronzing or decolorizing reagent in glass manufacture; in the manufacture of opal glass and enamels, and for various other purposes.

Artificial Ageing. The application to an alloy, previously given a solution treatment (q.v.), of a low-temperature treatment, when structural changes, due to partial transformation of the super-saturated solid solution, result in increased strength and hardness, as compared with the normal alloy. The term should properly be restricted to the treatment of alloys which will not age-harden at room temperature. The use of a similar treatment to accelerate age-hardening, in alloys which *will* harden at room temperature, should be termed "accelerated ageing".

Asterisms. In Laue photographs of strained crystals, the radial "smears" developed by the extension of the circular spots, indicating either local curvature of the lattice planes, or the disintegration of the crystal into a mosaic of smaller fragments, having a circular grouping and of varying orientation.

Atom. The smallest unit quantity of an element that, so far as can be determined by ordinary chemical analysis, is capable of entering into combination to produce either elements or compounds. By the use of extra-chemical means, however, the a. can be further disintegrated. The modern conception of the a. is that it consists of an electrical structure, with which mass is associated, in which there is a minute central core or nucleus, composed essentially of free protons, together with the proton-electron pairs known as neutrons, surrounded by extra-nuclear free electrons, situated at different distances from it. Although the neutrons and protons which chiefly compose the nucleus are at different energy levels, and therefore not invulnerable to change, only radioactive transformations can effect any change in the nucleus. Electrons as such are not structural units in the nucleus. Since the mass of the electron is only about $\frac{1}{1844}$ that of the proton, and all the protons are contained, in one form or another, in the nucleus, this is responsible for almost the whole mass of the a. The external free electrons, being situated at varying but relatively great distances from the nucleus, are responsible for nearly the whole of the volume of the a., which has a radius of the order of 10^{-8} cm. The free electrons are arranged round the nucleus in a series of rings or "shells", each shell being composed

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of electrons with the same principal quantum number (q.v.), the method by which the successive shells of the different elements are built up being given under Electronic Structure (q.v.). Only those free electrons which comprise the outermost shell are concerned in the usual chemical reactions, the nucleus being unaffected. An element of atomic weight W and atomic number N has a nucleus of $W-N$ neutrons and N protons, controlling N free electrons. The a. of oxygen (at. wt. 16 : at. no. 8) consists of a nucleus of 8 neutrons and 8 protons surrounded by 8 free electrons. The a. of bismuth (at. wt. 209 : at. no. 83) consists of a nucleus of 126 neutrons and 83 protons controlling 83 free electrons. Each proton carries a positive charge of 4.77×10^{-10} e.s.u., and each electron a negative charge of the same amount. The neutron, being the combination of a proton and an electron, carries no charge. Electrons are identical from one atom to another, and the number in any atom is exactly that required to balance the positive charge on the nucleus. The nuclear charge determines the number and arrangement of the extra-nuclear electrons—the atomic number—and, almost identically, their energies in binding to the nucleus. The charge on the nucleus consists of integral multiples of the fundamental electron unit, and varies from the unit itself, in the light hydrogen nucleus, to 92 times this unit, in the heaviest nucleus known, that of uranium, a fact accounting for the assumed existence of only 92 chemical elements. Isotopes (q.v.) are elements having the same nuclear charge, but different nuclear masses. Ions (q.v.) are atoms which have either lost or gained electrons, and have thus become positively or negatively charged, respectively.

Atomic Composition. In an alloy, the number of atoms of a metal present in 100 atoms of the alloy. For a binary alloy, if the percentages by weight of the two metals, X and Y , are p and $(100 - p)$, the a. weights w and v , and the a. percentages q and $(100 - q)$, respectively, then :

$$q = \frac{100 p}{p + \frac{w}{v} (100 - p)}$$

and

$$p = \frac{100 q}{q + \frac{v}{w} (100 - q)}$$

The *equivalent a.c.* is the a.c. multiplied by the valency.

Atomic Energy. As usually understood, the release of great amounts of utilizable e. by a. bombardment. This process has much vogue in popular estimation, but it is most unprofitable when per-

formed in the physical laboratory. The chief difficulty is that much more e. has to be put into the process than can ever be got out. Certainly, one of the isotopes of uranium, upon bombardment by neutrons, could be made to disintegrate with the liberation of a good deal of e., but this isotope is exceedingly rare. Up till now, no other material has shown any promise of furnishing a profitable supply of a.e.

Atomic Fall. A value obtained by dividing the depression of the freezing point of a metal resulting from the addition of a small amount of another metal by the a. percentage of the added metal.

Atomic Heat. The numerical product of the a. weight and the specific h. of an element. According to Dulong and Petit's Law (1819), the a.h. has an approximately constant value of 6.4 for many solid elements when measured in the customary units. Thus the a.h. of nickel is: $58.69 \text{ (a. wt.)} \times 0.109 \text{ (sp.h.)} = 6.40$. Some elements with low a. weights appear to be exceptions to this law if one uses the specific h. value at ordinary temperatures; but, by taking that at a higher temperature, an approximation to the law is once more obtained.

Atomic Mass. See A. Weight.

Atomic Number. The ordinal number of an element in the series of the elements arranged in accordance with the Periodic Law (q.v.). It is either the number of external free electrons in the atom, or—since the atom as a whole is neutral—the number of free protons in the nucleus. These numbers may vary from 1 for the light hydrogen atom to 92 for uranium, the heaviest atom known. Except for the light hydrogen atom, the nucleus of any element contains, in addition to the free protons, one or more proton-electron pairs, or neutrons, sufficient in number to make up the difference between the a.n. and the atomic mass. The atom of bismuth (a. wt. 209; a.n. 83) consists of a nucleus of 126 neutrons and 83 protons controlling 83 planetary electrons. In representing a nuclear disintegration by an equation, it is advisable to write the a.n. or nuclear charge as a subscript, and the mass number or atomic weight as a superscript, on the left-hand side of the atomic symbol, thus $^{209}_{83}\text{Bi}$. Except for hydrogen, the a.n. is never more and is usually less than half of the atomic weight.

Atomic Projectiles. Particles of high energy used in the bombardment of the nucleus, to effect artificial disintegration. Among such are α -particles, deuterons, electrons, neutrons, positrons,

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protons and radiation quanta. Charged a.p. moving with enormous speed can be produced by electrical discharges or other suitable means and accelerating them by strong electric fields in a high vacuum. A charged particle passing freely between two points whose potential difference is 1000 volts is described as a 1000-volt electron, proton or other particle. The energy of the electron or other particle is thus conveniently expressed in electron volts. By laboratory means, charged particles with an energy of 1,000,000 volts can thus be produced. By employing the high velocity α - and β -particles emitted by radioactive substances, the energy can be increased to 10,000,000 electron volts. The transmutation of an element by artificial means was first effected by Rutherford in 1919, using α -particles from radioactive substances to transform nitrogen into the isotope of oxygen of mass 17, with the emission of a proton.

Atomic Transformation. See Transmutation of Elements.

Atomic Volume. The a. weight of an element divided by its specific gravity in the solid state; or the number of c.c. occupied by the a. weight, expressed in grams. The hardness of a metal appears to be closely related to its a.v., the hardest metals being in general those of smallest a.v., hardness being proportional with the quantity a/v^2 , where a is Van der Waals' constant—the coefficient of mutual attraction of the particles, or the value of the attraction for unit v —and v is the a.v.

Atomic Weights. The relative average masses of the atoms of elementary substances referred to a common standard, usually that which assigns to the oxygen atom an a.w. of 16.00. Nearly all a. masses are then almost exactly whole numbers. On the same basis, the a.w. of the lightest atom, that of hydrogen, is 1.00778. The a.w. of an element depends almost entirely upon the number of protons in its nucleus. Such protons may either be free, or combined with electrons to form proton-electron pairs, or neutrons. All atoms are composed finally of protons and electrons, and, since the mass of the electron can be neglected, all a.w. should be multiples of that of hydrogen. But if the a. mass of hydrogen is taken as 1, all the heavier atoms show significant deviations from whole numbers. To explain these divergences, it is postulated that the closely packed arrangement of the nuclear particles in the heavier atoms alters their energy so greatly as to affect their mass appreciably, this packing effect being nearly constant throughout the whole Periodic System (q.v.). The mass of the nucleus is therefore less than the total of the masses of its constituent particles in the free state, this "mass defect" being a measure of the binding energies existing between

the nuclear particles. It is obviously more convenient, however, to base a.w. on oxygen = 16 than on hydrogen = 1.00778. It thus becomes useful to distinguish between nuclear mass, the exact mass in terms of the chosen unit, and nuclear mass number, the integer to which the number expressing the exact mass very closely approximates. Even on the basis of oxygen = 16, some a.w., as that of chlorine (a.w. 35.46), are far removed from whole numbers, this being explained by the existence of isotopes (q.v.). The recorded a.w. of an elementary substance which is in reality complex, consisting of a mixture of isotopes, is the weighted average of the a.w. of the isotopes. The existence of isotopes thus makes it necessary to include the word "average" in the original definition. The actual weight of the individual atom can be determined if the number of atoms in a given gross weight of some elementary substance is known. Thus, 1 c.c. of hydrogen at normal temperature and pressure has a weight of 0.00009 gm. and contains 5.4×10^{19} atoms, the mass of the hydrogen atom being thus 1.66×10^{-24} gm. Since 16 gm. of oxygen contain 6.06×10^{23} atoms, a single atom of oxygen must weigh 26.4×10^{-24} gm. The actual weights of the atoms of other elements must be in equivalent proportions. The weight of the heaviest atom known; that of uranium (a.w. 236), is 392×10^{-24} gm.

Atomisation. In Powder Metallurgy, the dispersion of a molten metal by gas or liquid pressure into small particles which solidify upon cooling (A.S.M. Defn.).

Austempering. A patented heat treatment involving the controlled hot-quenching of steel (or cast iron), which has previously been heated above the transformation range, so as to give rise to austenite, in a molten salt or lead-bismuth bath held at a substantially uniform temperature between 500° and 650° F. (260° and 343° C.). The steel is kept in the bath and a considerable proportion of the austenite is allowed to transform isothermally before allowing to cool to room temperature. The salt-bath temperature is below that at which pearlite is produced (1000° F. or 538° C.), and above that at which martensite is produced (400° F. or 204° C.). The resultant product is bainite (q.v.), which is free from the internal stresses attending the formation of martensite, and also exhibits an unusual combination of ductility, strength and hardness. Steel so quenched shows a ductility considerably greater than when quenched and tempered in the usual manner to give an equivalent hardness. The maximum thickness of steel that can be austempered successfully varies with the carbon content, and for a 0.9 per cent. carbon is about $\frac{1}{4}$ in. See also Critical Cooling Rate, S-Curve, Split Transformation of Austenite, etc.

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Austenite. A non-magnetic solid solution of carbon, or more probably of Fe_3C , in γ -iron. In alloy steels, other carbides may be present. Above their critical range, all steels consist entirely of a. Its structure shows a light-coloured mass of polyhedral grains which resemble those of a pure metal. A. is an interstitial solid solution, having a face-centred cubic lattice, in which the lattice positions are occupied only by iron atoms, the smaller carbon atoms being contained in the spaces inside the cubic cells. Below the critical range, a. is extremely unstable, but it can partly be retained at normal temperatures in high-carbon steels quenched very rapidly from a high temperature. In cooling plain carbon steels to about 690°C ., a. is transformed into the eutectoid, pearlite, a mechanical mixture of ferrite and cementite. The addition of such elements as manganese and nickel tends to lower the critical temperature; and, if present in sufficient quantity, may even depress it below atmospheric temperature, thus enabling the a. to be wholly retained in the cold. These austenitic alloy steels have many important industrial applications.

Austenitic Cast Irons. A range of high-nickel c.i., often containing copper and chromium in addition, austenitic at normal temperatures. Niresist (or Nimol) the best known of these, contains 12-15 per cent. nickel, 5-7 per cent. copper, 1.5-4 per cent. chromium, 1.25-2.0 per cent. silicon and 2.75-3.0 per cent. carbon. This alloy is a., with inclusions of graphite and carbide, non-magnetic, and shows high resistance to corrosion by sea water, caustic liquors, acid mine waters, etc. It has many applications for pump parts, marine castings, boiler fittings and the like. Up to a temperature of 800°C . or somewhat higher, it has an excellent resistance to scaling and growth, being inferior in this respect, however, to the high-silicon heat-resisting irons (q.v.), as Nicrosilal, which are also a., but are weaker and less readily cast and machined than Niresist.

Austenitic Steels. S. used industrially having a structure composed substantially of austenite. By the addition of suitable proportions of nickel or other appropriate alloying elements, the $\gamma \rightarrow \alpha$ transformation temperature can gradually be lowered, as required, even down to atmospheric temperature; when the s. remains a. even after slow cooling. To avoid carbide precipitation and consequent embrittlement, however, a.s. are often quenched from a high temperature. A.s. are non-magnetic and readily work-harden. The most important are the 11-14 per cent. manganese wear-resisting s. and the 18:8 chromium-nickel stainless s.

Auto-Frettagé. A cold-working process for increasing the strength of gun-barrels, tubes, pressure vessels, hollow cylinders, etc., by means of stresses caused by plastic radial expansion. The radial deformation may be effected either with or without longitudinal tension. The strength of rotating wheels can also be increased by previous overloading.

B

Bailey's Creep Test. This determines the creep characteristics of any steel required for high-temperature service by a series of tests based on a maximum permissible creep of 0.001, with a life period for first-line service of 100,000 hours, equivalent to an average rate of creep of 10^{-6} per hour. For example, tensile creep determinations are made for constant stresses of 16, 10, 6, 2 and 1 ton per sq. in., at various temperatures for each stress, to enable the relation between temperature and time to be derived for a total creep of 0.001 in. By plotting for each stress, with the ordinate representing temperature, while the abscissa is the logarithm of the time to produce a strain of 0.001—times which may either be measured directly or extrapolated—curves are obtained which, when extrapolated for a period of 100,000 hours, enable one to derive the temperature at which the particular stress will result in a total creep of 0.001 strain in 100,000 hours. Calculating similarly the results for each stress, one obtains a stress-temperature relation giving, for the various temperatures, the constant stress resulting in a total creep of 0.001 strain. Such stresses may be regarded as safe working stresses for the arbitrary "life" of 100,000 hours; while the stresses for other rates of creep, as may be required, or permitted, in service, can be similarly determined.

Bainite. A decomposition product of austenite, produced when transformation occurs at temperatures between about 200° and 500° C. B. is intermediate in character between martensite and troostite, and is obtained by quenching a small sample of eutectoid steel, in the austenitic state, in a bath of molten lead or salt maintained at a constant temperature within this range, and leaving in this bath until transformation is complete. If the bath is at the higher temperature—a temperature just below that at which troostite is produced—the b. ("upper" b.) has a feathery structure composed of ferrite and cementite. If the bath is at the lower temperature—a temperature just above that at which martensite is produced—the b. ("lower" b.) is acicular, resembling martensite, but differing from it in method of formation and development; although indistinguishable from martensite which has been tempered for a long time at the same temperature. Intermediate varieties of b. are produced at intermediate tempering temperatures.

Balanced Reaction. See Reversible Reaction.

Band Spectrum. See S.

Bar

Banded Structure. A segregated s. in mild steels, showing bands, parallel with the direction of working, alternately of ferrite only (usually containing a higher proportion of phosphorus and non-metallic inclusions) and of the usual ferrite-pearlite s., typical of mild steel. Steels showing b.s. have usually low impact values and are mechanically inferior to normal steels, but they machine more readily.

Bar. Finished steel (q.v.), obtained by cogging and rolling (or sometimes hammering) from the ingot or billet (q.v.). B. is of no very well-defined size. Such steel, when smaller than a certain size, may be termed *rod*; and, above another size, *bloom* (q.v.). Other alloys are also produced in the form of b. by various methods.

Barba's Law, which states that geometrically similar test pieces deform similarly, is that on which the standardization of tensile test pieces is based. Thus, cylindrical specimens in which the ratio of gauge length to cross-sectional area is constant, will show approximately similar elongations. For cylindrical bars, the relation almost invariably used, and adopted by the British Standards Institution, is as follows: If L is the gauge length, and A the cross-sectional area of the mid-portion of the test piece, then $L = 4\sqrt[3]{A}$.

Barff Process. A rust-proofing process for iron and steel parts, which are subjected at a red heat to the action of steam, so as to produce a coating of magnetic oxide of iron (Fe_3O_4).

Barium. Ba. El. A.W. 137.36; At. No. 56; S.G. 3.66; M. Pt. 704°C . Silvery white or yellowish soft and malleable "alkaline earth" metal, spontaneously inflammable in moist air and resembling calcium chemically. Occurs naturally as *barytes* or *heavy spar* (BaSO_4), *witherrite* (BaCO_3), etc. Extracted by heating b. hydroxide to a high temperature with aluminium, and subsequent separation by distillation. Used in the radio industry to clean up the last traces of gas in vacuum tubes, as a barium-nickel alloy for automobile ignition equipment, and (with calcium) in ternary lead bearing alloys.

Bark. The decarburized skin or layer just beneath the scale (A.S.M. Defn.).

Barr-Bardgett Creep Test. A t. which determines the diminishing rate of c. in a stressed t. bar by means of a steel weigh-bar, so that the c. in the t. bar is accompanied by a proportionate decrease in the applied stress. The results of tests on different samples of the same material tested under varying loads at the required temperature

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are plotted as stress-time curves, showing that the initial stress is approximately proportional to the decrease of stress in a given time. By plotting these against each other, extrapolation towards the initial stress axis should determine the stress resulting in no measurable decrease in stress during the t . period, corresponding, within the limits of refinement of the apparatus used, to a c . value not greater than 7×10^{-6} per in. for the t . period of 48 hours; or 1.45×10^{-7} in. per in. per day.

Base Metals. A term surviving from the days of Alchemy, when it was used to describe those m .—copper, lead, tin, etc.—which corrode or oxidize on exposure to air, moisture or heat; as distinct from the *noble m .*—gold, platinum, etc.—which are not so affected. Still sometimes used to denote the m ., of negative electrode potential, at the lower end of the Electrochemical Series ($q.v.$).

Basic Steel. S . melted under a b . (lime) slag in a furnace having a b . (magnesite or dolomite) bottom and lining, by which means good-quality s . can be made from high-phosphorus pig irons, otherwise unsuitable for s . making. The other constituents are also removed, but the charge should be low in silicon, because removal of the phosphorus requires the presence of a strongly b . slag, and too much silicon also causes waste of lime and unduly prolongs the process. Again, manganese is removed only slowly by contact with b . slag, so that the content of this should also be low. When the phosphorus has been sufficiently reduced, the slag is removed; otherwise, the necessary deoxidation of the metal by ferro-manganese, ferro-silicon or other deoxidizers would cause the return of phosphorus to the s . Deoxidation replaces the soluble iron oxide by insoluble oxides or silicates, which separate to a considerable extent from the liquid metal, but may also be found to a varying extent as non-metallic inclusions in the solid s . Since the degree of oxidation of the bath is greater than in the acid s . process, the content of non-metallic inclusions in $b.s.$ may be greater, particularly when deoxidation is effected in the ladle, and the time available for separation of the deoxidation products is thus diminished. These statements refer in general to the more usual b . open-hearth process.

Beilby Layer. The surface l . of amorphous metal produced by polishing a metal or alloy. This l ., which may cover the whole surface, may be regarded as an undercooled highly viscous liquid. It must be removed by etching, before the underlying structure can be revealed.

Bend Test. A means of evaluating ductility, usually in steel. A test piece of specified dimensions and suitable length is bent, gener-

ally in the cold ; either, as is preferable, by steady loading in a testing machine, or by a series of hammer blows, over a former of specified radius and through a specified minimum angle of deflection—both the radius and angle being varied with the carbon content and mode of manufacture of the steel—without fracture, or any signs of cracking. Again, the liability of a steel to hot-shortness—lack of ductility at higher temperatures—can be determined by a bend test made at the appropriate temperature.

Beryllium. Be. El. A.W. 9.02 ; At. No. 4 ; S.G. 1.82 ; M. Pt. 1284° C. Hard white brittle metal, which in the pure (distilled) state can be forged and hot-rolled to some extent, but becomes brittle again on cooling. Has a great affinity for oxygen. Occurs as *beryl* ($3\text{BeO} \cdot \text{Al}_2\text{O}_3 \cdot 6\text{SiO}_2$). Obtained by the electrolysis of a mixture of b. fluoride and oxyfluoride in a graphite crucible, the cathode being a water-cooled iron tube, which is slowly raised during the process, so that the b. is deposited in rod form. Used for the windows of X-ray tubes, electrodes for neon signs and targets for cyclotrons and as a deoxidizer of cast copper. Its chief use is as a constituent of various copper and nickel alloys, to which it imparts pronounced age-hardening properties. B.-aluminium alloys, by reason of the serious casting difficulties, and low strength and creep resistance, are useless in aircraft construction.

Bessemer Process. A p. for making steel in a B. converter by blowing air at some 20 lb. per sq. in. through liquid pig iron. The excess impurities are oxidized and removed, the heat evolved by these exothermic reactions, and the rapidity with which the process is completed, maintaining the reduced steel at a high temperature. In the acid p., the converter is a pear-shaped tilting vessel, some 9 ft. in diameter and 12 ft. high, lined with ganister, the bottom perforated with holes some $\frac{3}{4}$ in. in diameter. The converter is turned on its side and molten pig iron run in, containing some 2 per cent. of silicon. After righting, the blast is turned on, oxidizing the silicon and manganese to an iron-manganese silicate, which floats on the metal ; and the carbon to carbon monoxide, which burns with an intense blue flame at the converter mouth. The process takes some 12–18 minutes, when the steel is deoxidized and recarburized by the addition of the necessary amount of spiegel (q.v.), and poured. The acid B.p. is used to a limited extent for making steel for rails, axles, tyres, springs, etc., and some alloy steels. In the basic B. or Thomas process, which takes some 25 minutes, there are two distinct stages, the *fore-blow*, in which silicon, manganese and carbon are oxidized ; and the *after-blow*, after the flame from the converter has dropped, in which period the phosphorus is removed. To maintain temperature, a content of

Bet

some 1.5-2 per cent. of phosphorus is required in the charge, and the slag must be skimmed off before the recarburizer is added, or the phosphorus may partly be liberated again and returned to the charge. The basic B.p. is used in the U.K. for the manufacture of low-carbon welded tubes; while on the European continent it is extensively used for the manufacture of ship plates, structural sections, etc. The B.p. is obviously not so amenable to control as the open hearth p. (q.v.), and there are some minor differences in the quality of the steel; but, when properly controlled, steel of perfectly reliable quality can be made by either B.p.; and, for some purposes, each is superior to the open hearth p., *e.g.*, acid B. steel for case-hardening purposes and basic B. steel for welded tubes.

Beta Iron. Formerly, a supposed allotropic form of α -iron, stable between A_2 and A_1 , *i.e.*, about 770° and 900° C., of body-centred cubic form, almost incapable of dissolving carbon, and only very feebly magnetic. In reality, the change in magnetic intensity of α -iron occurring at about 770° C. is not associated with any structural transformation, and β -iron is no longer recognized as a distinct variety.

Beta Particle. A high-velocity electron (q.v.) spontaneously emitted from the nucleus of a radioactive element. In β -p. disintegrations, the neutron is considered to be transformed into a proton within the radioactive nucleus, an electron being ejected. The velocity of emission varies with the disintegrating element and may sometimes equal that of light, 186,000 miles per second, being in other cases some 40 or 80 per cent. of this. β -rays consist of a stream of β -p., and have a penetrating power at least 100 times that of α -rays.

Bethanizing. A process of zinc-coating wire carried on by the Bethlehem Steel Co. of America. The zinc is deposited electrolytically, the wire itself being the cathode; while the anodes are a silver-lead alloy. By regulating the speed of passage of the wire, which is passed continuously through the electrolyte, a solution of zinc sulphate, the weight of the deposit can be accurately adjusted to between 0.4 and 2.4 oz. per sq. ft.

Billet. A semi-finished rolled ingot of rectangular cross-section, the width being always less than twice the thickness, of cross-section ranging from about 4 to 36 sq. in. Smaller sizes may be classed as bars or "small billets".

Binary. Consisting of two components (q.v.).

Binary Alloy. An alloy containing two principal elements (A.S.M. Defn.).

Binder. In Powder Metallurgy, a cementing medium (A.S.M. Defn.).

Bismuth. Bi. El. A.W. 209.00; At. No. 83; S.G. 9.82; M. Pt. 269° C. Hard, brittle, greyish white metal with a reddish tint, and bright metallic lustre. A very bad conductor of heat and electricity. Diamagnetic. Expands on solidification; as also do bismuth-rich alloys. Occurs free, and as *bismuth glance* (Bi_2S_3), *tetradymite* (Bi_2Te_3) and *bismite* or *bismuth ochre* (Bi_2O_3). Extracted by roasting the sulphide to oxide and reducing this with charcoal in crucibles or a reverberatory furnace. Used in fusible alloys, solders, to promote machinability in stainless steels, and for other purposes.

Black Annealing. This process is variously described in official definitions, two of which are cited: (1) A process of annealing sheets, prior to tinning, in boxes which impart a black colour to the surface of the product. The term is also used in the manufacture of other products when no special precautions are needed to ensure that the annealed product is free from scale or discoloration (A.S.M. Defn.). (2) A process of box annealing iron-base alloy sheets after hot-rolling, shearing and pickling. The process does not impart a black colour to the product if properly done. The name originated in the appearance of the hot-rolled material before pickling and annealing (Proposed Std. Defn., A.S.T.M., 1942).

Black Body (or Ideal Radiator). A b. having no reflecting power and therefore capable of absorbing all radiations incident upon its surface, for all values of the w.-l. of the incident radiant energy. A uniformly-heated furnace viewed through a small aperture approximates to true b.b. conditions, the same applying to any hot b. inside it. If a hot b. is out in the open, and its surface has appreciable reflecting power, the radiant energy it emits will be less than that of a true b.b. at the same temperature, this b.b. coefficient or emissivity (q.v.) depending upon the w.-l., temperature and kind of surface.

Black Heat Range. A somewhat indefinite temperature r., covering temperatures sensibly above the normal up to that of a just visible red (about 525° C. when viewed in the dark).

Blank. (1) A piece of metal specifically prepared for manufacture unto some particular object. (2) In Powder Metallurgy,

Bla

a pressed, presintered, shaped, cut or sintered compact of powdered metal, usually in the unfinished condition (A.S.M. Defn.).

Blast Furnace. A tall vertical steel shaft f., lined with refractory bricks, supplied with an air blast (usually hot) delivered through tuyères near the bottom, and used for the production of pig iron (q.v.) by the smelting of iron ore. The other raw materials are coke, both for heating and the reduction of the oxide to metal; and limestone, to remove the earthy matters in the ore in the form of a fluid slag, which floats on top of the metal. The raw materials are charged at the top, and the pig iron and slag tapped from the bottom at intervals. The pig iron may be cast into pigs, or delivered in a molten state to the steel f.

Blending. See **Mixing**.

Blister. A defect in metal produced by gas bubbles either on the surface or formed beneath the surface while the metal is hot or plastic. Very fine blisters are called pinhead or pepper blisters (A.S.M. Defn.).

Blister Bar (Blister Steel, Converted or Cemented Bar). Steel made from wrought iron by the cementation process, the bar iron being packed in cast-iron boxes with charcoal and heated in a furnace at a temperature of 850°–1000° C. for periods varying from 7 to 11 days, according to the carbon content required, which may vary from about 0.75 to 1.25 per cent., the bars being then allowed to cool down very slowly in the furnace. During the process, blisters are raised on the surface, due to the expansion of the soft iron by gas formed during the process. B.b. forged down under the hammer or rolled at a yellow heat are known as "plated bars" or "bar steel". When piled and forged together, plated bars are used in the manufacture of shear steel; or, when melted in crucibles and cast into moulds, for making crucible cast steel.

Bloom. An ingot which has been rough-hammered down to a cross-section greater than 36 sq. in., whether the section is square or rectangular.

Blowhole. A term used to describe almost any defect in cast metal originating as entrapped air or steam from the mould; or by the release of absorbed gases or of gases produced by reactions between constituents of the metal occurring during solidification. The viscosity of the metal has prevented the release of these before solidification has occurred, and b. may thus be either superficial or deep-seated. B. differ from shrinkage cavities (q.v.) in having a smoother surface, and, frequently, in being more discoloured.

Blue Annealing. A process of a. iron-base alloys, usually as sheets or strips, after rolling ; the surface being blued by passing the sheets singly through an open furnace in which they are heated to a suitable temperature in air or steam. *See also Temper Colours.*

Blue Brittleness or Blue Shortness. (1) Usually, a property of tool steels when hammered or swaged in the temperature range giving rise to a blue temper colour (approx. $300^{\circ}\text{C}.$, but the b.b. range may extend from about 200° – $450^{\circ}\text{C}.$), when very fine cracks, almost indistinguishable by the naked eye, may be caused. (2) As sometimes understood, a property of steels which have been tempered or annealed within much the same temperature range, and then have a reduced impact value in the cold. This effect may be due to the precipitation of oxides or nitrides to the grain boundaries, for it is shown very little by aluminium-treated steels.

Blued. *See Blueing.*

Blueing. (1) The heating of steel to the temperature (about $300^{\circ}\text{C}.$ for a straight carbon steel) at which the surface acquires a blue oxide film, thus indicating a definite degree of tempering (q.v.). Heating caused by mechanical work, as grinding, may give rise to the same colour. *See also Temper Colours.* (2) A blue-black finish on steel can also be obtained by chemical methods, as by simmering at a temperature of 138° – $140^{\circ}\text{C}.$ in a solution of 20 oz. potassium nitrate and 20 oz. of caustic soda in 1 pint of water. Gun barrels are also blued by a chemical process.

"Body." A somewhat doubtful and indefinite quality sometimes attributed to cast irons, and considered to depend more upon the method of manufacture than upon the chemical composition.

Bond (Link or Linkage). In representing the graphic or structural formula of a compound, hyphens or lines drawn from the symbol of an element, to represent the number of valencies (q.v.) which it possesses (*e.g.*, water, H_2O or $\text{H}-\text{O}-\text{H}$). Where two or more valencies of an atom unite with an equivalent number of another atom of the same element, these multiple b. are sometimes represented by dots (*e.g.*, ethylene, C_2H_4 or $\text{H}_2\text{C}:\text{CH}_2$; more usually $\text{CH}_2:\text{CH}_2$).

Bonderizing. A method of priming the surfaces of steel parts to produce a coating of manganese phosphate, increasing the adhesion of paint, enamel or lacquer. Processing is very similar to that for Parkerizing (q.v.) in respect of composition and temperature of the bath; but accelerators are added, reducing the time required to

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some 4–10 minutes. In a later development of B., as in the Parkerizing D process, zinc instead of manganese phosphate is used, when the addition of accelerators reduces the processing time to some 3–6 minutes.

Bonnet. A spongy formation produced at the top of a steel ingot which has been poured from unkilld steel, and due to the copious release of gas while the metal is in a pasty condition.

Boron. B. El. Non-metal. A.W. 10.82 ; At. No. 5. *Amorphous* b. is a dark-brown infusible powder of s.g. 2.6, unaffected in air at ordinary temperature. *Crystalline* or *adamantine* b. is a very hard black solid (m. pt. 2300° C.), obtained by fusing amorphous b. with aluminium at 1500° C., and frequently regarded as a compound. Occurs as *borax* or *tincal* ($\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$) ; *colemanite* ($\text{Ca}_2\text{B}_6\text{O}_{11} \cdot 5\text{H}_2\text{O}$) ; *boracite* ($2\text{Mg}_3\text{B}_6\text{O}_{18} \cdot \text{MgCl}_2$) ; *boronatrocaltite* ($\text{CaB}_4\text{O}_7 \cdot \text{NaBO}_2 \cdot 8\text{H}_2\text{O}$), etc. Extracted by heating b. trioxide with magnesium ; when, on treating with hydrochloric acid, the brown powder is obtained. This is purified by treatment with hydrofluoric acid, and fusion with B_2O_3 in a stream of hydrogen. Calcium boride, made by the electrolysis of a fused bath of lime and b. oxide, is used in the deoxidation of copper, brasses, bronzes, etc. In steel, b. in amount not exceeding 0.003 per cent.—added as an alloy with other elements, to protect the b. from oxidation—increases hardenability, which is then comparable with that obtained by larger additions of scarcer alloys, e.g., molybdenum. In excess (over 0.03 per cent.), b. causes hot-shortness, by the production of brittle films of $\text{Fe}_3\text{C} \cdot \text{Fe}_2\text{B}$. In cast iron, in proportions of 0.02–0.10 per cent., b. tends to inhibit graphitization, giving increased surface hardness and depth of chill (e.g., in chilled rolls).

Box Annealing. A process of annealing which is carried out in a suitable closed metal box or pot to prevent oxidation. The charge is usually heated slowly to a temperature below the transformation temperature range and cooled slowly. It is also called **Close Annealing** or **Pot Annealing**. (Prop. Std. Defn., A.S.T.M., 1942.)

Box Pile. In manufacturing wrought-iron bars, a pile, the outside of which is formed of flat bars and the interior of a number of small bars, all bars running the full length of the pile. (A.S.T.M. Std. Spec. A81—33.)

Bracketing. In the construction of an equilibrium or constitution diagram, the determination of a transformation temperature by rapid quenching of samples of the alloy at temperatures respec-

tively above and below that temperature, followed by microscopic examination of the quenched specimens, which show, in each case, the structure existing at the moment of quenching. By quenching further specimens over a narrower range, and still further ones, as necessary, the transformation temperature can be exactly arrived at.

Brasses are substantially zinc-copper alloys which may contain other elements to impart special properties. The straight b. fall into the following classes, according to their microstructure: (1) α -brasses, containing—under equilibrium conditions—up to some 39 per cent. of zinc, soft and ductile, very amenable to cold working by rolling and drawing. Cannot normally be worked hot. Used for condenser tubes, etc. (2) $\alpha + \beta$ brasses, containing some 39-46.5 per cent. of zinc, harder, stronger and less ductile, used chiefly as casting alloys. Owing to the brittleness of the β -constituent, cannot be cold-worked successfully, but very suitable for hot working by rolling and extrusion. (3) β -brasses, containing some 46.5-49.5 per cent. of zinc, stronger but less ductile than those of $\alpha + \beta$, used only as casting alloys. (4) $\beta + \gamma$ brasses. Alloys containing more than about 49.5 per cent. of zinc show, as well as β , the white γ -constituent, which is very hard and brittle. Alloys containing more than a minute proportion are commercially unusable. Other metals added to brass have an effect resembling—and either greater or less than—that of zinc. The relative “zinc equivalence” of any such metals must be calculated before estimating the probable microstructure (see Guillet’s **Equivalent, High-Tensile Brasses and Manganese Bronze**).

Brazing (or Hard Soldering). A process of joining by partial fusion the surfaces of similar or dissimilar metals or alloys by the insertion of a copper-zinc (or copper-zinc-silver) alloy of lower m. pt. The surfaces to be joined must be free from oxide films, as is ensured by the use of a flux (generally borax) with a m.pt. lower than that of the b. alloy. The process usually involves temperatures of some 750°-900° C. B.S.S. 263—1931 covers three grades of b. solder: AA (60 per cent. copper : 40 per cent. zinc ; m. pt. c. 900° C.) ; A (54 per cent. copper : 46 per cent. zinc ; m. pt. c. 890° C.) and B (50 per cent. copper : 50 per cent. zinc ; m. pt. c. 880° C.). The m. pts. of the alloys can be reduced and the fluidity increased by the addition of silver in quantity from 10 to 50 per cent. The joint strength obtained by b. is much greater than in the ordinary soft soldering process (q.v.) and may be as high as 40 tons per sq. in. The so-called “copper brazing”, used for securing high-speed steel or sintered carbide tool tips to mild steel shanks, employs, instead of brass, metallic copper, in conjunction with a boric acid or other suitable flux ; or even, by using a reducing atmosphere, without

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a flux. Hard soldering also covers the use of ferro-manganese as the "brazing" alloy, in conjunction with a suitable flux, this method being also employed for tool tipping.

Bridging or Scaffolding. (1) In a shaft furnace, the consolidation or binding together of a layer of charge, so as to form a bridge or arch across the furnace in one position. The overlying layers are thus prevented from descending to the melting zone; while a cavity is produced by the descent of the layers of charge below the bridge. (2) In Powder Metallurgy, the formation of arched cavities in a powder mass which results in voids in the sintered compact (A.S.M. Defn.).

Bright Annealing. An annealing process which is usually carried out in a controlled furnace atmosphere so that surface oxidation is reduced to a minimum and the surface remains relatively bright. (Prop. Std. Defn., A.S.T.M., 1942.)

Bright Steel. (1) S., usually in bar or strip form, which, after hot-rolling to a convenient size, and then pickling to remove the scale produced in hot rolling, is finished by rolling or by drawing through dies in the cold, resulting in a bright instead of a black surface. Such s. has greater strength and lower ductility than usual. (2) S. produced from ordinary black s. by processes of turning or grinding, when the properties remain unaffected.

Brinell Hardness Test. The Brinell test for determining the hardness of metallic materials consists in applying a known load to the surface of the material to be tested through a hardened steel ball of known diameter. The diameter (or depth) of the resulting permanent impression in the metal is measured. The Brinell hardness number is taken as the quotient of the applied load, divided by the area of the surface of the impression, which is assumed to be spherical :

$$\text{B.H.N.} = \frac{P}{\frac{\pi D}{2}(D - \sqrt{D^2 - d^2})}$$

where B.H.N. = Brinell hardness no.,

P = applied load in kilograms,

D = Diam. of the steel ball in millimetres, and

d = diameter of the impression in millimetres.

If the steel ball were not deformed under the applied load and if the impression were truly spherical, then the above formula would be a general one, and any combination of applied load and size of ball could be used. As the impression is not quite a spherical surface

(since there must always be some deformation of the steel ball and some recovery of form of the metal in the impression), for a standard Brinell test the size and characteristics of the ball and the magnitude of the applied load must be standardized. A standard ball 10 mm. in diameter and a load of 3000 kg. for hard metals and 500 kg. for soft metals is standard practice (A.S.T.M. Std. Method of Test for Brinell Hardness of Metallic Materials, E10—27).

Briquette. (1) A block or other shape of convenient standard size, obtained by compressing a mass of smaller particles, to which—in order to make them stick together—a binding material is added. Briquetting is commonly applied to small coal, where the binder is pitch; but it is also used for many other materials. Metal turnings are briquetted to reduce bulk and facilitate charging to the furnace, and re-melting. Ferro-alloys are briquetted so that each contains a given quantity of the alloy, when a definite amount of the alloy can readily be added to a melt by counting briquettes instead of having to weigh them. (2) In Powder Metallurgy, b. is synonymous with *Compact* (q.v.).

Brittleness. (1) The quality possessed by materials which break suddenly, with little previous deformation, when loaded. In this sense, b. is the opposite of ductility (q.v.). B. must not be confused with lack of strength. Some brittle materials, as many varieties of cast iron, have a high tensile strength. (2) That quality of materials characterized by a low value in a notched-bar test. Low notched-bar values are often shown by materials of high ductility. In this sense, b. is the opposite of toughness (q.v.). See also **Notch B.**, **Temper B.**, etc.

Bronze. An alloy of copper and tin, usually containing either zinc or phosphorus as a deoxidizer. In the second case, the alloy is termed phosphor b. (q.v.). Zinc b. may also contain varying proportions of lead; from that present only as an impurity up to, frequently, 5–6 per cent., and sometimes much more. The best-known b. is Admiralty Gunmetal, containing 88 per cent. copper, 10 per cent. tin and 2 per cent. zinc, an alloy of excellent castability and high performance for many engineering duties; among its advantages being its resistance to salt-water corrosion and its excellence as a bearing alloy. Its microstructure shows isolated patches of the hard $\alpha + \delta$ eutectoid, set in a softer matrix of α -solid solution. For reasons of war economy, this general-purpose alloy was replaced first by the 87 : 9 : 3 : 1 and then the 86 : 7 : 5 : 2 alloy, these figures denoting the proportions of copper, tin, zinc and lead, respectively. Lower proportions of tin (4–8 per cent.), with higher proportions of zinc (up to 5 per cent.) and often 10–25 per cent. of

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lead, have long been used for b. for steam valves, pressure-resisting purposes and unlined bearings subject to hard wear; as also for backing metal for lined bearings. Some of the tin in b. can be replaced by nickel, and b. in which the contents of tin and nickel are together greater than 10 per cent. are used for locomotive slide valves, steam valves, cocks and similar fittings exposed to the action of steam, the alloy containing 7 per cent. nickel and 11 per cent. tin being particularly suitable for this purpose. Alloys containing higher proportions of nickel, up to 30 per cent., show excellent resistance to corrosion. Nickel-b. which do not contain zinc require the addition of a suitable deoxidizer.

Brunorizing. The trade name for a special treatment applied to rails which, after cooling to a temperature below the transformation range, are reheated to a temperature slightly above that range, and then are allowed to cool in the air, the ends of the rails being partially quenched by jets of compressed air. (Prop. Std. Defn., A.S.T.M., 1942.)

Buffing. The production, on metals or alloys, of a mirror-like surface by the action of fine abrasives and high speeds, in the presence of some sticky material, as beeswax. It is essential that friction is employed and considerable heat is always generated. The material of the buff is leather of soft but tough grain, tanned by a special process known as oil tannage. Bullneck, buffalo or walrus hide are commonly employed. The removal, by etching, of the surface layers of a buffed specimen always reveals scratches, which have been filled up with "smeared" or "altered" metal; while no scratches should be found on etching a metal surface which has been polished metallographically.

Bulging (or Drifting) Test. A ductility t. for copper and brass tubes and pipes, where the tube must withstand bulging or drifting, without showing either crack or flaw, until the diameter of the bulged or drifted end measures not less than 25 per cent. more than the original diameter of the tube.

Bulk Modulus (or M. of Volume Elasticity). The resistance to compression when a uniform pressure, p , is applied to the whole surface of a solid of original volume V_1 and final volume V_2 , given by the expression $pV_1/V_1 - V_2$.

Burning. The overheating of steel—as in preparation for forging or rolling—to a temperature sufficiently close to the melting point to lead to permanent injury. While the usual overheating gives rise only to a coarse structure which can be corrected by normalizing

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(q.v.), a grosser overheating may cause melting of the more fusible constituents and the segregation of these to the grain boundaries, where oxides may also be produced. Thus severe intergranular weakness is set up, such as may give rise to cracking, often of a honeycomb type, either if the material is further worked, or if it is quenched in heat treatment. Steel in this condition is quite useless and fit only for remelting. A similar effect, leading to incipient fusion at the grain boundaries, is found in brass annealed at a temperature close to that of the solidus, such metal being so deteriorated as to be unusable except after remelting.

Burnishing. A method of polishing metals, either by hand with hardened and polished b. tools or smooth bloodstones or agates ; or in rotating barrels containing hardened steel shot. The high pressure and/or rubbing contact causes the surface metal to become smooth, and present an apparently polished surface. B. differs from tumbling (q.v.), in which a cutting action is set up, either by the parts themselves, or through the medium of a cutting agent.

Burnt. *See* **Burning.**

Bushelling. In the manufacture of wrought iron, the process of heating to a welding heat in a reverberatory furnace, miscellaneous iron, steel or a mixture of iron and steel scrap cut into small pieces. (A.S.T.M. Std. Spec. A81—33.)

Butt. (1) The end surface of a bar ; or the edge or vertical surface of a plate. (2) The operation of bringing two such surfaces together, *e.g.*, as a preliminary to welding.

C

Cadmium. Cd. El. A.W. 112.41; At. No. 48; S.G. 8.65; M. Pt. 321° C. A silvery-white ductile and malleable metal. Occurs as the rare *greenockite* (CdS), but commonly found in zinc, lead and copper ores, where it is a recoverable by-product. C. is the first product in the distillation of zinc ores, being obtained as a deposit of cadmiferous blue powder—partly metal, partly oxide, and containing up to some 8 per cent. of c.—in the condensers and prolongs. The resulting crude c. is separated from the remaining zinc by repeated distillation at a low temperature, or by electrolysis with a crude c. anode and a pure c. cathode in a solution of c. chloride or sulphate, the c. being dissolved from the anode and re-deposited on the cathode. C. is used as an electrodeposited rust-proofing coating on iron and steel. C.-base alloys containing silver and copper are used for particular bearings. C. is a constituent of fusible alloys, soft solders, brazing solders, and as a 1 per cent. addition to copper for such conductors as trolley wire, to increase strength.

Cæsium. Cs. El. A.W. 132.91; At. No. 55; S.G. 1.87; M. Pt. 28.45° C. Soft silvery-white alkali metal; the most basic and electropositive metal known. Occurs as *pollux* or *pollucite*, a c. aluminium sodium silicate; and in small quantities in *carnallite*, *beryl*, etc. Obtained by the interaction of c. chloride or carbonate with magnesium or calcium in the presence of hydrogen, and in the pure state by electrolysing the cyanide; also produced (in thermionic-valve factories) by the dissociation of barium nitride at about 150° C. in the presence of c. chloride. Used in the manufacture of photoelectric cells and thermionic valves. The c. cell is about fourteen times as sensitive as the older hydrogenated potassium photoelectric cell.

Cake. In Powder Metallurgy, a mass of weakly coalesced metal powder resulting from the reduction of metal oxides (A.S.M. Defn.).

Calcium. Ca. El. A.W. 40.08; At. No. 20; S.G. 1.55; M. Pt. 810° C. Silvery-white "alkaline earth" metal, so soft that it can readily be cut by a knife. Very reactive. Occurs as *limestone*, *marble* and *chalk* (CaCO₃); *gypsum* or *selenite* (CaSO₄.2H₂O); *fluorspar* (CaF₂), and in other minerals. Extracted by the electrolysis of fused anhydrous c. chloride at a temperature of 780°–800° C., when metal of 98.4–98.6 per cent. purity is obtained. By sublimation *in vacuo*, metal of 99.5 per cent. purity can be obtained. C. is

used as a deoxidizing agent in many alloys ; and to inhibit carbide formation and control grain size in special steels. Lead-c. alloys are used for bearing purposes, cable sheathing, and grids and plates for storage cells.

Calorizing. A process for treating iron and steel parts by heating to a temperature of 900° – 1000° C. in stationary or rotary retorts in contact with finely-divided aluminium. A surface layer of aluminium-iron alloy is obtained ; and, outside this, a layer of aluminium oxide, having a very high fusing point. The combination is very resistant to oxidation at high temperatures, and c. is therefore commonly applied to mild steel carburizing boxes, pyrometer sheaths, pre-heater tubes, etc.

Carbide Stabilizers. See Stabilizers.

Carbo-Nitriding. A process of case-hardening an iron-base alloy by the simultaneous absorption of carbon and nitrogen by heating in a gaseous atmosphere of suitable composition, followed by either quenching or cooling slowly, as required. (Prop. Std. Defn., A.S.T.M., 1942.)

Carbon. C. El. A.W. 12.01 ; At. No. 6. Non-metal. Occurs in several allotropic forms, crystalline as *graphite* and *diamond* ; and amorphous as *charcoal*, *anthracite*, *gas-carbon*, *lamp-black*, etc. C. is an essential constituent in steel, in proportion varying with the purpose, being present as cementite or iron carbide in slowly-cooled steels, and as solid solution of c. in γ -iron in quenched steels. In cast irons, which contain usually between 2.5 and 4.0 per cent. of c., it occurs partly as free c. (graphite) ; partly as cementite ; the varying distribution of the c. between these two forms considerably influencing the strength and hardness. Metallic carbides are hard and brittle, those of tungsten and titanium being constituents of sintered cutting tools.

Carbon Steel. S. which owes its properties chiefly to its c. content and contains no appreciable amounts of other alloying elements ; known also as "Ordinary S." or "Straight C.S." According to the Alloy Steels Research Committee, "carbon steels are regarded as steels containing not more than 1.5 per cent. manganese and 0.5 per cent. silicon, all other steels being regarded as alloy steels".

Carbonization or Carbonizing. The process of coking, or driving off the volatile matter from coal, wood, etc. C. should not be confused with "Carburizing" (q.v.).

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Carbonyl Powder (or Carbonyl Particles). In Powder Metallurgy, a metal powder prepared by the thermal decomposition of metal c. (A.S.M. Defn.).

Carburizing, Carburization, Case Carburizing or Cementation. The impregnation of a surface layer of low carbon steel (*e.g.*, C. percentage 0.15 (max.)) with additional carbon, usually up to about 1 per cent., by heating the metal above its critical range in contact with solid, liquid or gaseous media, known as carburizing compounds or carburizers (q.v.). The term "carbonizing", sometimes used in this sense, is incorrect, and its use should be discouraged. C. is the first operation in Case-Hardening (q.v.). In the usual or solid-c. process (sometimes termed pack-hardening), the parts are packed in heat-resisting boxes, filled with carbonaceous materials, and heated, out of contact with the air, at a temperature of 900°–925° C. Parts of the article not requiring to be case-hardened are protected by coating with copper, or otherwise. Alternatively, the carbon-rich case is removed before hardening, the necessary machining allowance being made to provide for this. In all c. processes, the depth of case varies directly with temperature, time and the nature of the carburizer.

Carburizing Compounds or Carburizers. (1) Solid carburizers are porous mixtures consisting of grains, all of standard size, of wood charcoal, coke of various kinds, charred leather, charred bone, etc., with salts of the alkali and alkaline earth metals, to serve as energizers during the process, probably acting as catalysts in the $C : CO_2 : CO$ reaction, to increase the amount of carbon monoxide liberated, this gas being that chiefly responsible for the c. effect. (2) Liquid carburizers contain sodium or calcium cyanide as the activating agent, and sodium carbonate, sodium chloride, calcium chloride or other diluent, to stabilize the cyanide and thus reduce the operating cost.

Case. The surface layer of a steel part which has been suitably altered in composition and made substantially harder than the interior or core by a process of case-hardening. In the ordinary c.-hardening process, either the c. after carburizing, or that after final hardening, may be intended.

Case-Hardening. The complete process of carburizing (q.v.) low-carbon steel, followed by subsequent quenching, so as to produce an article which, by virtue of the high-carbon case, has a hard wear-resistant exterior; but, by virtue of the low-carbon core, is tough and ductile in the interior. Quenching after hardening is frequently done successively at two temperatures, a higher one of 900° C. to

refine the core, and a lower one of 760° – 780° C., to refine and harden the case. C.-h. is commonly used for the manufacture of camshafts, gudgeon pins, etc., where such respective properties are required. Processes which resemble c.-h. are flame-hardening, induction-hardening, nitriding, etc.

Cast Iron. A cast alloy of i. and carbon, with other elements, and any carbon content in excess of about 1.8 per cent., the maximum solid solubility of carbon in i. at any temperature; therefore containing eutectic carbide (white c.i.), graphite (grey c.i.) or both (mottled c.i.). It is not usefully forgeable at any temperature. In practice, c.i. usually contains from 2.5 to 4.5 per cent of carbon, although the content may exceptionally be still less or greater. I.-carbon alloys containing up to about 1.8 per cent. of carbon solidify completely as austenite, a solid solution of carbon in γ -iron. In alloys containing more than 1.8 per cent. of carbon, *i.e.*, those coming within the category of c.i., after the separation of austenite containing 1.8 per cent. of carbon in solid solution, there is a residual liquid which solidifies with a carbon content of 4.3 per cent., at a constant temperature of 1130° C., as the austenite-cementite eutectic. The production of this eutectic, known as ledeburite (q.v.), constitutes the essential difference between c.i. and steel. In practice, c.i. usually contains 0.5–3.5 per cent. of silicon, which affects the solid solubility of carbon in i.; the limiting solubility, for example, being about 1.5 instead of 1.8 per cent. in the presence of 2 per cent. of silicon. Although cementite (Fe_3C) is always produced in the primary solidification of c.i., it is unstable and—on slow cooling and in the presence of sufficient silicon—readily breaks down into i. plus graphite. Graphite is the characteristic feature of grey c.i., which is comparatively soft and machinable. The brittle flakes of graphite break up the continuity of the very much stronger metal, and its quantity and distribution considerably influences strength and machinability. If insufficient silicon and enough sulphur and manganese are present, the i. will be white, hard and unmachinable even on slow cooling; or, again, on rapid cooling even with a high silicon and low sulphur and manganese contents. By subsequent annealing, the graphite can be made to separate, as in making malleable c.i. (q.v.). Grey c.i. consists of flakes of graphite set in a matrix of composition varying with combined carbon content, and consisting of ferrite and pearlite, in i. with less than 0.85 per cent. of combined carbon (hypo-eutectoid); pearlite only, in those containing 0.85 per cent. (eutectoid); and pearlite and cementite, in those containing more than 0.85 per cent. (hyper-eutectoid). The presence of other constituents may lead, however, to an all-pearlite matrix with less than 0.85 per cent. of combined carbon. I. which are mainly ferritic are soft and weak; those mainly pearlitic harder

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and strong. All high-strength c.i. have thus a pearlitic matrix. I. containing a substantial proportion of free cementite are much harder, but are comparatively weak and brittle. *See also Austenitic C.I., Heat-Resisting C.I., High-Duty C.I., Inoculated C.I., Lanz Perlit I., Malleable C.I. and Martensitic C.I.*

Cast Steel. The term applies strictly to any object made by pouring molten steel into a mould. Any steel casting must evidently be made of "C.S.". The description is applied particularly, however, to Crucible Steel, as used for making high-carbon tools.

Castability. The ability to be cast successfully.

Casting. (1) The production of a metal object, directly in one operation, by utilizing the hydrostatic pressure of molten metal so as to cause the material to take the shape of a mould which has been previously prepared. (2) The object so produced. *See also Centrifugal C., Chill C., Die C., etc.*

Catalysis. A process in which the speed of a chemical reaction is modified by the presence of a small proportion of another substance which *apparently* takes no part in the reaction, and can be recovered unaltered in character and amount at the end of the reaction. Catalytic agents can initiate, accelerate or retard the velocity of a reaction, and c. may therefore be either positive or negative. It is probable that the presence of the catalytic agent results in the temporary formation of one or more unstable compounds involving the catalyst and one or more of the reacting bodies. *See also Poisoning.*

Catalytic Agent. A reagent employed in catalysis, as nickel or palladium in the hydrogenation of fatty oils.

Cathode (or Kathode). The negative electrode in an electrolytic cell; the electrode by which a direct current leaves the liquid.

Cathode Ray. A type of radiation accompanying the passage of a high-potential electric charge through a vacuum tube, giving rise to a "stream" of negatively-charged cathode particles or electrons. The ratio of the electric charge, e , to the mass, m , is constant for all electrons, independent of the nature of the electrodes or of the gas in the discharge tube. The value of $\frac{e}{m}$ is about 1.758×10^7 e.m.u./gm. The velocity of cathode particles varies, according to the difference of potential across the terminals of the discharge tube,

from about 10^9 to 10^{10} cm. per second—about $\frac{1}{30}$ to $\frac{1}{3}$ of the velocity of light. They move in straight lines, but are capable of being deflected by a magnet, and can penetrate thin sheets of metal. They can be produced in various ways, as in the hot filament of a wireless valve, by the action of ultra-violet light on certain metals, in a photoelectric cell, or by a spontaneous high-speed emission from radioactive substances. *See also X-Ray Tube.*

Cation (or Kation). Positively charged ion, resulting from the loss, by a neutral atom, of an electron. In electrolysis, c. migrate to the negatively-charged cathode. *Cf.* anion.

Caustic Embrittlement. An e., as of steel boiler plates, due usually to the use of water containing an undue concentration of caustic soda and accelerated by the presence of severe mechanical stresses within the steel. A characteristic effect is that of inter-crystalline cracking along the ferrite grain boundaries. Under boiler conditions, sodium carbonate, inevitably present in softened waters, is hydrolysed to caustic soda, and gives rise to the same reaction. The concentration of alkali may arise from leakages at rivets and seams; but even a high caustic concentration will not cause e. except when severe mechanical stress is also present. This may be set up by mal-aligned rivet holes, and in other ways. Why steel is thus affected is uncertain, and the successful use of inhibitors, such as sodium sulphate and other substances, cannot yet be satisfactorily explained.

Cellular Structure. A surface s. which is sometimes superimposed on, and sometimes apparently replaces, the normal crystalline surface s. of a cast metal or alloy. The s., which is characteristic of colloid or gelatinous substances, resembles the polygonal s. of a pure metal, but arises in a different manner. Increased viscosity in the liquid retards the normal process of crystallization; and, under suitable conditions, the distribution of convection currents caused by temperature differences due to unequal cooling may become extremely regular, approaching to an arrangement in regular hexagons of equal size. This c.s. may be retained by the solid, as with colloid substances. The surface s. of any solid is thus governed partly by the forces of crystallization and partly by the mode of circulation of the liquid. Either of these factors may predominate, and one may be absent entirely. Strongly crystalline metals, as antimony and bismuth, have very little tendency to develop c.s.; but others, as lead and tin, may show surface s. of both kinds superimposed. A c. surface s. affords no evidence of any such internal partitioning of the mass.

Cem

Cementation. Any process in which iron or steel is heated in contact with carburizing materials so as to absorb carbon in the outer layers, *e.g.*, carburizing or case-hardening. The term is applied particularly to the conversion of bar iron into "blister steel" (q.v.).

Cemented Bar. *See* Blister Bar.

Cementite. Iron carbide, Fe_3C , containing 6.67 per cent. of carbon, an intensely white, very hard (Brinell hardness, 600 upwards) and brittle compound, and the usual form in which carbon occurs in annealed or normalized steels, and in white cast irons. C. is one constituent of the eutectoid, pearlite (the other being ferrite); and, in hyper-eutectoid steels, it occurs also as free c., either as a network at the pearlite grain boundaries, or as lamellæ within the crystals themselves. In carbon steels, part of the iron in c. is replaced by manganese; and, in alloy steels, by other elements, as chromium or tungsten. C. is not a stable compound, and on prolonged annealing may decompose into iron plus free carbon (graphite).

Centrifugal Casting. The casting of metal under pressure due to the centrifugal force developed by rotating a specially prepared mould at high speed. Pipes, gear blanks, etc., are frequently so made; while the lining of bearing shells with white metal is often effected in a similar manner.

Cerium. Ce. El. A.W. 140.13; At. No. 58; S.G. 6.92; M. Pt. 630° C. Soft steel-grey "rare earth" metal. Occurs, with thorium, in *monazite sand*; and in other minerals. Obtained by electrolysis of the fused chloride. Used as a gas purifier in the manufacture of neon lamps; as a c.-iron alloy in "flints" for automatic lighters; in aluminium alloys for grain refining.

Chafing Corrosion. *See* Fretting C.

Change Point. *See* Transformation.

Chapmanizing. A process, somewhat resembling nitriding, in which steel parts are heated, not in a gas, but in a liquid bath at about 1500° F. (815° C.), to produce a surface layer, from 0.002 to 0.3 in. deep, containing nitrides, of Brinell hardness 700 to 1100.

Charcoal Pig Iron. P.i. made in a blast furnace fired with c., and therefore much purer than ordinary p.i. It is made to the extent of some 100,000 tons per annum (U.S.A.—1943), and used chiefly in malleable castings, chilled rolls and wear-resistant castings. In chilled rolls, it is used to keep down the manganese and silicon

content of the charge; otherwise the greater oxidation required in the furnace results in a highly oxidized metal with a serious reduction in carbon content. In cupola practice in general, the employment of c.p.i. enables the use of a much higher proportion of scrap. Scarcity of c. limits its production.

Charpy Impact Test. A standard method of i. testing (q.v.). The t. piece is 100 mm. square, 50 mm. long, with a central slot 1 mm. wide, 5 mm. deep, drilled to a diameter of 1.3 mm. at the bottom of the slot. It is supported as a simple beam (usually horizontal) with 40 mm. between the supports, and is broken by a single blow delivered horizontally midway between the supports, and struck so that the root of the notch is in the region of the tensile beam stress. The energy absorbed in fracturing the t. piece is determined. The formula for converting C. values in m.kg./cm.² to Izod values in the range of 15–70 ft.-lb. is: $I = 4.5C - 10$. For Izod values below about 15 ft.-lb. and above about 70 ft.-lb., respectively, C is less and greater, respectively, than that given by the formula. For further information on C.-Izod relationships, see the Addendum of March, 1942, to B.S.S. 131–1933. The test may be made on unnotched specimens, if indicated by the characteristics of the material tested.

Chemical Compound. See Compound.

Chemical Deposition. The replacement or precipitation of one metal from a solution of its salt by the addition of another metal or reagent to the solution (A.S.M. Defn.).

Chemical Element. See Element.

Chemical Properties. Those properties of a material which involve some change in its chemical composition.

Chemiluminescence. A variety of luminescence (q.v.) which requires the presence of oxygen or ozone for its production, as in that shown by phosphorus or the freshly cut surfaces of sodium and potassium. The "phosphorescence" shown by phosphorus is thus not strictly phosphorescence (q.v.).

Chill-Casting (or Chilling). A method of producing grey iron castings, certain faces of which must be hard and wear-resistant, these faces being caused to solidify as white iron by casting them against metallic chills set in the sand mould. The rapid abstraction of heat by the chill so accelerates the rate of cooling that the separation of graphite is almost entirely prevented, and an external layer

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of hard cementite is produced. The interior metal remains soft and tough. The depth of chill is varied to suit the service requirements. C.-c. is used in the manufacture of chilled rolls for mills, car wheels, the wearing parts of crushing machinery, etc. The term also covers the manufacture of cast bars, etc., by pouring into a split metal mould.

Chilling. (1) Synonymous with "Chill-Casting" (q.v.). (2) Sometimes used to denote rapid cooling in general, as by quenching.

Chills. The metal pieces set in the sand mould, or sometimes the separate metal moulds, used in chill-casting (q.v.). Denseners (q.v.) are sometimes described as "chills", but the purposes are quite distinct.

Chipping. One method of removing seams and other surface defects from partially worked material so that the defects will not be worked into the finished product. If the defects are removed by means of a gas torch, the term "deseaming" is used (A.S.M. Defn.).

Chrome-Hardening. See **Chromium-Deposition.**

Chromium. Cr. El. A.W. 52.01; At. No. 24; S.G. 6.74; M. Pt. 1830° C. Steel-grey metal, resembling iron; usually, through presence of carbide as an impurity, intensely hard; when pure, reasonably malleable and ductile. Occurs as *chrome iron ore* or *chromite* ($\text{FeO}, \text{Cr}_2\text{O}_3$), and in some rarer minerals. Extracted by the reduction of chromic oxide either by aluminium powder (Thermit process, q.v.) or by carbon or silicon in the electric furnace. The purest c. is obtained by the electrolysis of a solution of chromic chloride, using a mercury cathode, the amalgam being heated in a vacuum to remove mercury. Used as an electro-deposited coating on iron and steel parts for rust-proofing and wear-resisting purposes; in c. steels for armour plate and armour-piercing projectiles; c. and c.-nickel stainless steels, c.-tungsten high-speed steels, c.-silicon heat-resisting steels, nickel-c. structural steels, nickel-c. and nickel-c.-iron heat-resisting alloys, etc.

Chromium-Deposition (Chrome-Hardening or Hard Chromium Plating). C.-d. and c. plating are technically similar processes, but c.-d. on steel or cast iron is usually employed to obtain an abrasion- and wear-resistant layer; while c. plating is used for decorative or protective purposes. In c. plating, the deposited layer is very thin, only thick enough to polish. Further, the porosity of a c. deposit usually involves the previous plating of another metal, as nickel, there being otherwise insufficient protection of the basis metal. In

c.-d., the c. is deposited direct, the hardness obtained, up to 900 Brinell, varying with that of the basis metal, which must therefore be hard, so that copper and nickel are unsuitable. For abrasion resistance, the layer must be considerably thicker than for normal plating, usually at least 0.002 in. and often much greater, processing therefore taking much longer. The porosity of a c. deposit, giving an oil-retaining surface, is an advantage in c.-d., but a disadvantage in c. plating. By suitable variation in conditions, a more porous deposit may be obtained. The electrolyte is an aqueous solution of chromic acid containing sulphuric acid as a catalyst. Chromizing (q.v.) is a distinct process.

Chromium Steels. Cr dissolves in both α - and γ -iron, but it exists in s. chiefly as stable carbides, Cr_4C and Cr_7C_3 , which combine with the Fe_3C , to produce a complex carbide of great hardness and stability. In high-carbon s., a small proportion of Cr thus prevents graphitization. Cr also considerably reduces the quantity of carbon required to form the eutectoid, *e.g.*, to 0.62 per cent. with 2.8 per cent. of Cr; and 0.35 per cent. with 14 per cent. of Cr. Cr raises the critical range on heating, and also on cooling when this is slow. With more rapid cooling, the range is depressed, with resultant air-hardening (q.v.). Cr also assists grain growth, which must be avoided either by correct heat treatment, or the use of nickel or vanadium to prevent this effect. When present in proportions from 0.5 to 1.0 per cent., as in the pearlitic Cr s., Cr increases strength and hardness with little prejudice to ductility. Plain Cr s. are used, in the hardened and tempered state, for various purposes for which the quality of hardness is important, as for ball and roller bearings (C. 1.0 per cent.; Cr 1.5 per cent.); rock-crushing plant (C. 0.9 per cent.; Cr 2.0 per cent.); armour plate (C. 0.5–1.0 per cent.; Cr 1–3 per cent.), etc. With some 8 per cent. Cr, depending upon the carbon content, the a_{r1} point is depressed below atmospheric temperature, and the s. are troostitic or martensitic on slow cooling; showing also, with higher carbon contents, free cementite. Higher proportions of Cr, 12–14 per cent., are used in Stainless S. (q.v.). Cr in proportion from 8 to 33 per cent. is used in heat-resisting s. (q.v.), which often contain silicon, nickel and tungsten in addition.

Chromizing. The production, on suitable steels, of a corrosion-resistant case by heating the part, at temperatures between 900° and 1000° C., in gaseous chromium chloride; or in porous ceramic material previously saturated with chromium chloride. For the process to be entirely satisfactory, active carbide-forming elements, such as chromium or molybdenum, must be present in the steel. By heating for 1–2 hours at 1000° C., a case of about 0.005 in. in depth can be obtained, with a corrosion resistance of a high order.

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Cladding. A process for coating corrodible metals or alloys with more resistant ones by hot-rolling sheets of the two together, when a bonding is obtained such that no separation occurs during subsequent forming operations. Thus, steel may be clad with nickel, Monel metal, Inconel or stainless steel. The melting point of the c. material used must not differ greatly from that of the backing material. Aluminium cannot be clad on steel because it does not maintain its properties at the rolling temperature. It should be noted that Alclad, covering alloys of duralumin type coated with pure aluminium, is made by a somewhat different process, in which the casting mould for the aluminium alloy used is lined with sheets of commercially pure aluminium. The resulting billet is rolled into thin sheets, whose surface consists of pure aluminium, much superior in corrosion resistance.

Cleavage Planes or Cleavages. Planes, in one or more directions in a crystal, along which a fracture can be developed most readily, or, in the case of a ductile material, deformation, by slipping, most readily occurs. The positions of these planes vary with the crystal form. Thus, in the cubic system (q.v.), there are generally four c.p. parallel with the octahedral faces, but c.p. parallel with cubic faces may sometimes occur.

Clinking. The production of a crack (or "clink") on reheating a casting or forging, as when the local stresses due to unequal heating (which may be superimposed upon those already existing in the part) exceed those which can be sustained by the material. A similar effect may be obtained in cooling, especially with parts made up of sections of variable thickness, and particularly with rapid cooling, as in quenching. The term describes the sound which may be heard when failure occurs.

Close Annealing. Softening steel by heating it in a suitable closed metal box or pot to protect it from oxidation; also called box annealing or pot annealing (A.S.M. Defn.).

Cloudburst Process. (1) A hardness test involving the dropping of small hardened steel balls from a height so regulated that soft spots on the surface tested are seen as dull areas, the remainder being bright. By using only a few balls, the separate indentations can be measured. (2) The p. is similarly employed for the work-hardening of surfaces. (3) A very similar method (Chalmers, "Surface Hardness of Metals", *J. Inst. Metals*, 1941, LXVII, p. 295), used for the determination of the hardness of thin surface layers of metals and other materials, involves the use of a known quantity of grains of

sand or particles of emery, which are dropped from a standard height upon the surface to be tested. The particles are of varying shape ; and, within the screen limits, of varying size ; being also oriented at random upon impingement. The surface indentations therefore vary in shape and size ; but, by using a sufficient number of particles, the average shape and size of the pits depend only upon the hardness of the material ; and the number of indentations upon the amount dropped. The average size of the indentations is determined by measuring the reduction in the optical reflectivity of the surface. The method is particularly suitable for brittle materials, and where the hardness of the underlying metal may have a profound influence upon the result. Cases which defeat all the ordinary hardness tests, but are amenable to this method, are the very hard electro-plated white bronze coatings, the surfaces of polished and anodized metals, etc.

Co-ordinate Linkage. See **Electronic Theory of Valency.**

Coalescence of Cementite. See **Divorced Pearlite and Spheroidizing.**

Cobalt. Co. El. A.W. 58·94 ; At. No. 27 ; S.G. 8·79 ; M. Pt. 1460° C. Lustrous blue-white metal, with properties resembling those of iron ; after which it is the most magnetic metal known, retaining its magnetism at high temperatures, but becoming non-magnetic at 1115° C. Occurs as *smaltite*, $(\text{FeNiCo})\text{As}_3$; *cobalt glance* or *cobaltite*, $(\text{CoFe})\text{SAs}$, and *cobalt bloom*, $\text{Co}_3(\text{AsO}_4)_3 \cdot 8\text{H}_2\text{O}$. Usually obtained as a by-product in silver and manganese ores. Extraction is complex and difficult, the metal being finally obtained by reduction of the oxide with carbon in an electric furnace. The pure metal is prepared by the thermal decomposition of c. carbonyl or by electrolysis of a solution of c. sulphate, containing ammonium sulphate and ammonia. Used as a constituent in high-speed steels, sintered carbide cutting tools ; the cutting and hard-facing alloy, *Stellite* ; steels for permanent magnets, alloys for heating elements and other purposes.

Cogging. Rolling or forging ingots to reduce them to blooms (A.S.M. Defn.).

Cohesion. The force which holds together the chemically similar molecules of a material, enabling a solid body to maintain a definite shape and to resist without rupture the application of limited external forces. C. decreases with rise of temperature.

Coining. See **Sizing.**

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Cold Heading. A special method of upsetting (q.v.), used in the manufacture of rivets, bolts, etc., in which end pressure on the stock in the cold causes the metal to flow into a die so as to form the head of the part.

Cold Pressing. (1) *See Pressing.* (2) In Powder Metallurgy, the forming of a compact at room temperature (A.S.M. Defn.).

Cold-Rolled Strip Steel. This term covers a very wide range of material. After annealing, any amount of cold work can be done by cold rolling, ranging from a pass between the "levelling" or "breaker rolls", which does not appreciably reduce the gauge of the metal, on through various light "pincher passes" between planishing rolls, up to regular cold-rolling, that may affect as much as a 50 per cent. reduction in thickness. Every different amount of reduction produces a different set of physical properties. Differences in chemical composition, history of the steel itself, and its annealing, likewise cause variations in the final properties. . . . It is the established custom in the trade to classify this material rather roughly into five grades or tempers, ranging from No. 1, full hard, to No. 5, dead soft. Some manufacturers add a Grade No. 6, which is similar to Grade No. 5, but with special selection of chemical composition to attain the maximum of ductility. The demarkation between cold-rolled sheets and cold-rolled strip is as follows :

Cold-Rolled Sheets—Material over 12 to 24 in., inclusive, in width ; 0.0142 in., or over, in thickness, if no special edge, finish or temper is specified.

Material over 24 to 32 in., inclusive, in width ; 0.0142 in. or over in thickness.

Material over 32 in. in width, all thicknesses.

Cold-Rolled Strip—Material up to 12 in., inclusive, in width ; 0.2499 in. or under in thickness.

Material over 12 to 24 in., inclusive, in width, all thicknesses, if special edge, finish or temper, as covered in these specifications. (A.S.T.M. Std. Spec. A109—38.)

Cold Rolling. *See C. Working.*

Cold Shortness. Lack of ductility when worked in the cold, resulting in cracking or fracture. C.s. is shown by high-phosphorus steel, by high-sulphur steel which contains insufficient manganese (this alloy being also red-short) ; and may sometimes be due to the separation, on cooling, of a dispersed brittle phase at the boundaries of a quite ductile constituent.

Cold Shot. A defect, found particularly in cast iron, in which rounded shot-like particles of metal become embedded in the casting; due usually to splashing in pouring or incorrect gating of the casting.

Cold Shut. (1) An incomplete joint in a casting, due to the meeting of two streams of molten metal at a temperature insufficient for a complete joint to be made. In extreme cases, one advancing face may simply chill on the other, with little or no adhesion. A c.s. may at first appear to be a crack, or may develop into one. A special case of c.s. is the freezing over of the top surface of an ingot before the mould has been fully filled, due to interrupted pouring, such as may arise in the crucible process. (2) The term is sometimes used to describe a lap produced in rolling or forging.

Cold Working. Theoretically, permanent deformation of a metal or alloy below its recrystallization temperature, *e.g.*, for steel, at any temperature below the critical range, *i.e.*, below about 700°C . In practice, however, the term is usually restricted to temperatures approximating to that of the atmosphere, and in no case exceeding, say, 250°F . C.w. leads to a progressive distortion of the lattice structure, a progressive elongation of the grains in the direction of working; and, in extreme cases, to the breaking up of the grains into small fragments, variously oriented. C.w. usually leads to a progressive increase in strength and hardness, at the expense of ductility. The effects of c.w. may be increased by subsequent ageing (q.v.). C.w. also displaces the electrode potential in the negative direction, thus rendering the material less resistant to corrosion.

Colloid. Originally, a substance which, as distinct from a crystalloid (q.v.), cannot be made to crystallize from its aqueous solution; but now denoting a particular condition which many substances, *e.g.*, metals, can be made to assume. The difference between the two is chiefly in the size of the ultimate particles. Colloidal particles, although ultramicroscopic, are larger than single molecules, varying in size between the w.-l. of light (about $500\text{ m}\mu$) and average molecular size (about $1\text{ m}\mu$) and separated from each other by liquid, or air, as the case may be. The larger size of the particles explains the low osmotic pressure and much lower rate of diffusion of a c. than a crystalloid, as is utilized in the process of dialysis (q.v.) to separate one from the other. With suitable selection of conditions—solubility, concentration, viscosity of the solution and size and rate of diffusion of the particles—a given substance, for example, barium sulphate, can be obtained either as a crystalloid or c., as desired. A colloidal solution, or *sol*, is not a

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true solution, but a pseudo-solution, *i.e.*, a suspension of very fine undissolved particles, of size intermediate between those of true solutions and those of suspensions of solid matter in liquid. This apparent solution is not determinable as a suspension by the eye, but can be recognized as such by the opalescence seen when a strong beam of light is passed through the liquid. In evaporating a colloidal solution to "dryness", the solution coagulates or gelatinizes to form a *gel* or jelly, consisting of a mass of ultramicroscopic particles in which the "mother liquor" is retained by capillary attraction, and by the molecular forces exerted at the surfaces of the very great numbers of invisible particles. A metal can be obtained in colloidal solution, a suspension of minute electrically charged particles, either by the production of an electric arc between poles of the metal in water, or by the chemical reduction of a solution of one of its salts.

Columbium (*Syn.* Niobium). Cb. El. A.W. 92.91; At. No. 41; S.G. 7.37; M. Pt. 1950° C. Steel-grey metal, readily worked and welded; highly resistant to corrosion. Occurs as *columbite*, $\text{Fe}(\text{CbO}_3)_2$, often associated with the isomorphous *tantalite*, $\text{Fe}(\text{TaO}_3)_2$. Extracted by a complex wet process, and finally obtained by the electrolysis of the fused double c.-potassium fluoride. Used in the manufacture of chemical apparatus. Readily absorbs gases, and its use as a "getter" in vacuum tubes has been patented. As an addition in steel, c. forms a stable insoluble c. carbide, and it is therefore used, in amounts up to 1 per cent., in chromium steels, to prevent air-hardening and embrittlement; and, in stainless austenitic steels, to prevent weld decay (q.v.). In nitriding steels, the use of a similar proportion increases depth of case.

Columnar (or Fringe) Crystals. Elongated c., which grow from, and chiefly in a direction at right angles to, a cooling surface. The temperature gradient over some distance from the surface is too steep to permit of the separation of fresh nuclei, and lateral growth is prevented by the interference of adjacent c., so that c.c. are produced, and may even extend to the middle of the section. The joining of c.c. developing from two adjacent surfaces of an external right angle leads to a region, bisecting the angle, where the metal is last to solidify, and where impurities tend to segregate, when, in extreme cases, a crack may develop. Such external angles should therefore be radiused.

Combined Carbon. C. in any alloy which is not present in the form of "free" carbon or graphite. In steel or cast iron, c. existing in the form of iron carbide or cementite, Fe_3C .

Comminution. *See* Pulverization.

Common Iron. In the manufacture of wrought i., i. made from re-rolled scrap i. or a mixture of i. and steel scrap, no attempt being made to separate the i. and steel scrap. (A.S.T.M. Stds., A81—33.)

Compact (or Briquette). In Powder Metallurgy, an object produced by the compression of individual, mixed, or alloyed metal powders with or without the inclusion of non-metallic constituents (A.S.M. Defn.).

Components. (1) The substances, usually less complex than phases, making up the various phases constituting an alloy system. A c. is often a chemical element, and the constituent metals of an alloy are usually regarded as the c., a binary alloy thus having two c.; but a chemical compound may also be so considered. *See Phase Rule.* Cf. **Constituent.** (2) One of the plurality of more or less distinct laminæ that compose a given thermostat metal, and which, in co-operation with the other c., has a determining effect on the sensitivity to temperature of the thermostat metal in so far as tendencies to curvature change are concerned. (A.S.T.M. Stds., B106—40.)

Composite Metal. A combination of two metals or alloys by any method for any purpose. By this definition, both Electroplate and Sheffield Plate are c.m.; but the term is applied more particularly to the combination of a ferrous m. with either another ferrous or a non-ferrous m. An example is the coating of 18 : 8 chromium-nickel stainless steel on to ordinary steel for corrosion-resistant purposes, as in cladding (q.v.). The joint may be made in various other ways, however, as by casting the molten base m. against a solid alloy plate; casting the molten alloy on to a solid base m. plate, followed in either case by hot-working to the desired shape and size; while still other methods are employed.

Compound (Chemical C.). A chemically pure substance consisting of two or more elements united by chemical affinity in definite proportions by weight. Intermetallic c. (q.v.) may be formed directly from a homogeneous liquid solution, solidifying at a constant temperature; or may be rejected from a completely solid solution over a more or less extended range of temperature. They are usually hard, weak and brittle, but their presence in limited quantity may serve to harden and strengthen an alloy. *See also Electronic Theory of Valency.*

Compressibility. (1) Reciprocal of the bulk modulus, or modulus of volume elasticity (q.v.). (2) In Powder Metallurgy, the property of a metal powder to yield under pressure (A.S.M. Defn.).

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Compression Ratio. In Powder Metallurgy, the ratio of the volume of a loose powder to the volume of the compact after application of a specified pressure (A.S.M. Defn.).

Compressive Strength. The maximum compressive stress which a material is capable of developing. In the case of a material which fails in compression by a shattering fracture, the compressive strength has a very definite value. In the case of materials which do not fail in compression by a shattering fracture, the value obtained for compressive strength is an arbitrary value, depending upon the degree of distortion which is regarded as indicating complete failure of the material. (A.S.T.M. Std. Defn. E6—36.)

Concentration. The proportion in which a component may be present in a system. In solid and liquid metals and alloys, the proportion of a component is usually returned as a percentage by weight. The *critical c.* is the composition of the mixture of two metals, mutually soluble and existing together, when these become saturated with each other, so that both have the same composition, and only one solution is now present.

Conchoidal Fracture. A type of f. shown by amorphous solids, as glass or pitch, which break into irregular pieces with curved surfaces, showing concentric rings, as those on the inside of a shell.

Conjugate Solutions. Two s. existing together in equilibrium at a given temperature are termed c.s. A change in temperature causes a variation in the compositions and quantities of the s. C.s. are usually immiscible liquids, but may also be immiscible solid solutions, such as the constituents of a eutectic.

Consistency. The resistance to deformation of material. Quantitatively it is the ratio of the shearing stress to the rate of shear. (A.S.T.M. Std. Defn. E24—37T.)

Constituent. In the microstructure of an alloy, the various substances which can be metallographically identified. Annealed mild steel, for example, is an aggregation of two c., ferrite and pearlite; but may also show certain impurities, such as silicates and sulphides. Cf. **Component.**

Constitution. Structural make-up of a metal or alloy.

Constitutional Diagram. Since, in many alloys, equilibrium is not obtained in normal heating and cooling, the so-called equilibrium

d. frequently represents conditions which are partly metastable (q.v.), being therefore a c. rather than an equilibrium d.

Continuous Spectrum. See S.

Contraction. See Shrinkage.

Contraction of Area. See Reduction of Area.

Contrast Etching. E. so as to cause varying depths of attack, and thus differences in the colour of the different grains composing a polycrystalline aggregate, so that the grain size can readily be determined. Thus, c.e. by means of a picric-hydrochloric acid reagent is used to reveal, in martensite, the outline of the original austenite grains.

Controlled Atmosphere. Any gas or mixture of gases which prevents or retards the processes of surface oxidation and decarburization of steel parts during heat treatment. A c.a. may be provided by suitable combustion of the furnace fuel itself; or may be previously generated in a special plant outside the furnace, when it is sometimes known as a *protective a.*

Controlled Cooling. A term used to describe a process by which a steel object is cooled from the final hot forming operation in a predetermined pattern of cooling. (Prop. Std. Defn., A.S.T.M., 1942.)

Converted Bar. See Blister B.

Cooling (and Heating) Curve. A curve depending upon the observation and recording of time and temperature during the cooling (or heating) of a metal or alloy, and showing the temperatures at which transformations occur. In plotting such curves, the ordinate is usually temperature, θ , but the abscissa varies according to the method of plotting employed. For the Temperature-Time Curve (or Direct Curve), it is time, t . For the Inverse Rate Curve, it is $dt/d\theta$, the time taken for the temperature to fall through a given small interval of temperature. For the Difference or Differential Curve, it is $\theta - \theta'$, the difference of temperature between θ , the temperature of the sample being examined, and θ' , the temperature of another body, cooling under the same conditions, and showing no thermal transformation within the temperature range covered by the experiments. For the Derived Difference or Derived Differential

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Curve, it is $d(\theta - \theta')/d\theta$, i.e., the rate of change of the difference in temperature instead of the temperature difference itself. Inverse Rate and Derived Difference Curves show the temperature of transformation more clearly than do the other two curves.

Copper. Cu. El. A.W. 63.57; At. No. 29; S.G. 8.95; M. Pt. 1082.6° C. Salmon-pink metal, appearing often, by oxidation, more reddish; very malleable and ductile; of high thermal and electrical conductivity, second only to silver in these respects; tarnishes rapidly in air. Occurs native, and as *chalcopyrite* or *copper pyrites*, CuFeS_2 ; *erubescite*, Cu_2FeS_3 ; *chalcocite* or *copper glance*, Cu_2S ; *cuprite*, Cu_2O ; *malachite*, $\text{CuCO}_3 \cdot \text{Cu}(\text{OH})_2$; *azurite*, $2\text{CuCO}_3 \cdot \text{Cu}(\text{OH})_2$, and as other minerals. Extracted by complex processes which vary with the mineral and the locality. Thus roasted c. pyrites, in which oxidation of some of the c. and iron has resulted, is treated in a reverberatory or blast furnace with siliceous material, to produce c. *matte*, a mixture of cuprous and ferrous sulphides containing 20–75 per cent. of c. The process is repeated, to produce *white* or *fine metal*, consisting of nearly pure cuprous sulphide. The molten white metal is run into a tilting Bessemer converter and blown, to produce *blister c.*, containing 97–98 per cent. c., with some sulphur and iron; the blisters being due to the evolution of sulphur dioxide during solidification. Blister c. is converted by poling (q.v.) into crude c., which may finally be refined by electrolysis. Commercial c. is classified as follows: (1) high-conductivity electrolytic c.; (2) fire-refined c. sold, or intended to be sold, as high-conductivity c.; (3) high-grade fire-refined c.; (4) fire-refined c. of ordinary quality containing not less than 99.7 per cent. of c.; (5) fire-refined c. containing not less than 99.2 per cent. of c.; and (6) black hot-rolled c. wire rods. In universal use, chiefly in the electrical industry, as wire, rod and strip; extensively also in building, general engineering, railway, automobile and shipbuilding; while a wide range of copper alloys are employed in cast and worked forms. Among these are the bronzes, brasses, aluminium and manganese bronze, etc.

“Copper Brazing.” *See* Brazing.

Core. (1) The interior portion of a case-hardened steel article (whether after carburizing or after final hardening) and always substantially softer than the surface layer or case. (2) The inner portion of a bar or billet rolled from rimming steel, thus distinguishing it from the rim. (3) A body of sand, which is usually shaped in a separate former or core-box away from the mould, and then inserted into the moulding-box to form part of the mould, e.g., holes, recesses, and, in general, the interior portions of the casting.

Core Rod. In Powder Metallurgy, a member of a die assembly used to produce a hole in a compact (A.S.M. Defn.).

Cored Bar. In Powder Metallurgy, a compact of bar shape heated by its own electrical resistance to a temperature high enough to melt its centre (A.S.M. Defn.).

Cored Structure. That of a metal or alloy in which the interior or core has a structure differing from that of the exterior. Although a case-hardened article is evidently a c.s., the term is usually restricted to metallic crystals in which the rate of cooling has been so rapid that there is a gradual variation in composition from the middle to the exterior of each. Such variation can be corrected by sufficient subsequent annealing, when diffusion causes the material to become homogeneous.

Corrodible. Not resistant to the corrosion attack of a particular reagent, or reagents.

Corronizing. A rust-proofing process applied to woven wire cloth, thermostat elements, etc., and consisting of the electro-deposition of thin successive layers of nickel and zinc (the last being slightly thicker, and the total thickness about 0.002 in.), followed by annealing for several hours at 360° C., to cause diffusion between the two layers. The inner surface of the combined deposit usually remains as pure nickel; while above this are superimposed various zinc-nickel alloys.

Corrosion. The local destruction of metals or alloys by chemical or electrochemical agencies, as the rusting of iron. The term does not include the intentional solution of a metal or alloy in any reagent. C. results from the instability of metals and alloys, which tend to revert to a stable state by combination with surrounding elements. Liability to c. depends much upon the environment, a metal resistant to one set of conditions being readily attacked by another. Activity on the part of the environment is promoted by the presence of moisture, acids, dissolved chemicals, etc. C. may take various forms, as: (a) local c., or pitting, in which the surface shows pits or pin-holes, but the areas between these may be comparatively unaffected; (b) general surface c., in which the surface is attacked generally and not locally, this type being shown in the case of strong acid or alkaline attack on light alloys; (c) electrolytic or *galvanic* c., produced by contact with a dissimilar metal, alloy or other substance, with an electrode potential positive to that affected. A usual effect is intense pitting or furrowing in the region of contact; (d) inter-crystalline c., in which the surface may be comparatively unaffected,

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but there is selective attack along grain boundaries, sometimes promoted by the presence at these of particular constituents, as in the "weld decay" of austenitic steels. Combinations of two or more of these various types of attack are also found. Erosion may also be associated with c.

Corrosion Cracking. *See* Season Cracking.

Corrosion Fatigue. A type of failure of steels in which f. failure of the normal type—by means of a spreading crack—is preceded and initiated by an intense local corrosive attack, characterized by a very great extension in depth of surface pits, by a process of deep local "burrowing" into the metal, so as to give rise to sharp crevices. Finally, f. cracks of the normal type develop from the notches so produced. The resulting fracture is often, but not always, jagged. C.f. is shown particularly by mild steel pump shafts when exposed to the attack of sea water.

Corrosion-Fatigue Limit. Although such a value is sometimes quoted, it seems very doubtful, indeed, whether there is a true c.-f.l., failure occurring at very low stresses if the number of cycles is sufficiently high. The term is thus only an endurance l. for a given number of stress cycles. There is therefore no definite relationship between the c.-f. endurance l. and the tensile strength of the steel.

Corrosion Pits (or Figures). *See* Etch-Figures.

Corrosive. Of a reagent which may attack a particular material.

Covalency. *See* Electronic Theory of Valency.

Crackless Plasticity. A term given by H. F. Moore to denote that quality of a material by virtue of which it is capable of resisting, without failure, unlimited repetitions of stresses giving rise to a small amount of plastic strain. C.p. may have considerable influence upon the behaviour of machine parts, modifying to some extent the conclusions based upon the usual fatigue tests. Thus fatigue limits should no longer be regarded as purely elastic limits, because a component of plastic strain is involved. *See also* Damping Capacity.

Creep. The very slow but continuous regular plastic extension, even under comparatively small loads, shown by steels at temperatures over about 300° C., and probably due to viscous flow at the crystal boundaries, and/or, to slip within the crystals. At any given temperature, the rate of c. is approximately constant, but it varies from one steel to another. For different duties, differing

limiting c. rates are permissible, and thus the suitability of a steel for a particular duty depends upon its c. rate under the given service conditions. Alloy steels, as those containing molybdenum, show c. rates decidedly lower than with carbon steels. Ageing effects set up at the higher temperature may lead to a modification in structure and consequently in c. behaviour. *See also Limiting C. Stress and Permissible C. Rate.*

Critical Concentration. *See Concentration.*

Critical Cooling Rate. That rate of cooling through the critical range which is just sufficient to suppress a particular transformation. With steels, it is often necessary to prevent the austenite \rightarrow pearlite transformation, which occurs most readily at a temperature of about 550° C. If, by quenching, sufficiently rapid cooling is obtained as to avoid this, then, as the quench proceeds to lower temperatures, the steel transforms to martensite and is hard. By the addition of suitable alloying elements, as chromium or manganese, a great reduction in c.c.r. can be obtained, martensite being thus produced with considerably slower rates of cooling.

Critical Point. In a constitutional or equilibrium diagram, a point on the vertical line representing temperature, or the horizontal line representing composition, denoting the limit of the region occupied by a particular phase.

Critical Pressure. *See Critical Temperature.*

Critical Size. Of a plate or bar, the s. at which, after quenching, the unhardened core is just absent, *i.e.*, the s. which, according to the etch or fracture test, is just "hardened throughout".

Critical Solution Temperature. The t. at which two liquid phases, having only partial miscibility at lower t., reach the same composition, and thus become a single homogeneous liquid.

Critical Strain. That degree of cold working which particularly promotes the rapid growth of new crystals on subsequent annealing, greater or lesser degrees of deformation being much less effective in this respect. For any given metal or alloy, the c.s. varies with purity and grain size. C.s. is represented by about 2-4 per cent. elongation for iron, and 0.5 per cent. for aluminium.

Critical Temperature. (1) The highest t. at which a vapour can be liquefied by pressure, such pressure being known as the c. pressure, and the volume occupied by one gram of the substance the c. volume.

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(2) The t. at which a transformation occurs in a metal or alloy. In steels, the c. range or c.t. range is, usually, the t. range covered by the three arrest points, Ac_1 , Ac_2 and Ac_3 on heating; or Ar_3 , Ar_2 and Ar_1 on cooling. According to a proposed Std. Defn. of the A.S.T.M. (1942), a more suitable term is "Transformation Range" (q.v.). It will be noted that, by this interpretation, the c.t. range does not cover the A_{cm} point, although this is also a c.t.

Critical Volume. See **Critical Temperature.**

Cromodizing. A rust-proofing process for steel, a thin coating of iron chromate being applied.

Crop, Crop End or Discard. The end (or ends) of an ingot cut off and discarded, as containing the central pipe or other defects, the residual portion being then usually of sound metal. The amount of c. is frequently specified by the purchaser of the article to be forged from the ingot, *e.g.*, for forged steel shafts, 25 per cent. from the top and 5 per cent. from the bottom for poured ingots; and 10 per cent. from the top and 3 per cent. from the bottom for fluid-compressed ingots, which are sounder.

Crucible. (1) A small vessel, with a flat bottom, a circular cross-section and usually tapered and elongated, employed in gravimetric analysis. It is generally either of platinum or porcelain, but may be of other materials, as nickel. (2) A somewhat similar but very much larger vessel, with a capacity up to 1 ton, made of plumbago, and used to melt metals and alloys prior to casting.

Crucible Furnace. A metal-melting f. in which a c. is used. This f. may be either a pit in the floor, in which the c. is loose ("lift-out" c.); or may be a f. in which the c. is supported rigidly, and the whole f. suitably tilted for pouring. Pit-f. are usually coke-fired; tilting f. may be fired by coke, oil, gas or electricity.

Crucible Steel (Cast Steel or Crucible Cast Steel). Steel made by the crucible process, irrespective of carbon content, but usually containing some 1-1.5 per cent. of carbon. It is obtained by the carburization of high-grade wrought iron, which is cut into small pieces and melted in a crucible, with the addition of the appropriate amount of carbon. The product is cast into ingots and rolled into bars, used chiefly for high-carbon tool steels.

Crystal. A regular polyhedral form, bounded by planes, which is assumed by a chemical element, compound or other material, under the action of its intermolecular forces, when passing, under

suitable conditions, from the state of a liquid or gas to that of a solid. The crystallization of a new phase may occur in a body which is already solid. A c. is characterized by its definite internal molecular structure and its external form. The geometrical external form is assumed only when the c. can grow freely without interference. In a c. aggregate, this is prevented by the interference of adjacent growing c., but the regular internal structure of the c. is shown by the similarity of orientation in individual crystals, and in other ways. Theoretically, a c. is a periodic three-dimensional grouping in space of an enormous number of atoms, ions or molecules, held together by interatomic or intermolecular forces. The unit cell, which is the smallest portion of the c. containing all the groupings characteristic of the particular form of the substance, is very much smaller than the smallest visible crystal. The metallographically more important crystal systems (cubic, hexagonal and tetragonal) are separately defined.

Crystal Analysis. See X-ray C.A.

Crystal Growth. See Grain G.

Crystal Skeletons or Crystallites. The solid structure of a crystal in an early stage of growth, as may be shown by pouring off the remainder of the liquid metal after solidification has partly proceeded. The method of growth of the individual crystal, in relation to the crystal axes, becomes observable. This can also be seen on the free upper surface of solidified metal, where the skeleton axes, by reason of contraction, are left in relief.

Crystal Thrust. The t. exercised during the growth of a c. dendrite, which extends more rapidly in length than in breadth, the residual liquid incompletely filling the gaps between the dendrites, so that these regions are porous. The volume of the outer shell of the casting may thus be greater than its normal density would warrant.

Crystalline. Composed of crystals.

Crystalline Grain. See Grain.

Crystalline Nucleus. The minute solid particle deposited from a supersaturated solution; on which n., according to its particular form, the complete crystal is built up.

Crystallites. (1) Originally, and more usually, crystal skeletons (q.v.). (2) As used by some X-ray workers, the crystal fragments,

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with varying orientation, resulting from the breakdown of crystals severely deformed by cold work. (3) In some countries, the crystals themselves.

Crystallization. The separation, usually from a liquid phase on cooling, of a solid phase, appearing as differently-oriented independent crystals, each of which shows a similar structural arrangement within the individual grain.

Crystallization Interval. *See Solidification Range.*

Crystallography. The study of crystal forms, as of metals and alloys.

Crystalloid. A substance which crystallizes from its aqueous solution and is built up by a regular arrangement of its own molecules only. Each molecule, except those at the surface, is surrounded by other similar molecules. *Cf. Colloid.*

Cubic (Isometric or Regular) System. A s. of crystallization including all forms which are referable to three axes of equal length intersecting each other at right angles. The fundamental form is the regular octahedron (shown in the crystallization of silver, gold, platinum, iron and copper), other forms being the cube (iron) and rhombic dodecahedron (copper); while combinations of these forms often occur; as of the octahedron with the cube, termed the cubo-octahedron (lead).

Cup Fracture or Cup-and-Cone Fracture. A type of fracture, frequently seen in tensile test pieces of a ductile material, as mild steel, in which the surface of failure on one portion shows a central flat area of failure in tension, with an exterior extended rim of failure in shear. The extent of this rim is greater when the ratio of shear strength to tensile strength is lower. The fracture may thus form a complete cup, the other portion showing a corresponding cone. The terms "half-cupped" or "quarter-cupped" denote that this particular portion of the exterior is extended.

Cupola Furnace. In its simplest form, the c. is a straight vertical cylindrical shaft, made of iron or steel boiler plates riveted together, lined with refractory material and closed at the bottom, on which is a bed of coke. Above this are alternate layers of metal, limestone (to flux off the impurities) and coke, these being charged through an opening situated—for adequate preheating of the charge—at the highest practicable position, which is also that of the charging platform. Air for combustion of the coke is admitted through a

series of tuyeres in a horizontal ring round the c. at some little distance from the bottom, these being supplied by a wind-belt in which pressure is maintained, through a blast main, by means of a rotary blower or a fan. The molten iron falls through the coke bed and collects at the bottom, being tapped off as required, and delivered along a spout into the ladle. The slag collects above the metal and must be drawn off, before its level reaches to the wind-belt, through a slag-hole—some distance above the tap-hole—which is opened and closed as required. There is considerable resemblance, both in structure and mode of operation, between the blast furnace and the c. ; but, in the first, the chief purpose of the coke is to reduce the ore to metal ; while, in the c., its only purpose is to melt the iron.

Cuppiness or Cupping. A defect in the drawing of wire, which becomes hollow-drawn and shows fractures of the cup-and-cone type. It is due to excessive cold working before further annealing, the exterior skin, having been both extended longitudinally and subjected to considerable radial pressure, being thus enabled to withstand a much greater deformation than the unsupported interior metal, in which failure first occurs.

Cupping Test. A test to determine the deep drawing and pressing quality of sheet metal. A standard ball or plunger is forced into a sheet held between smooth clamps, the depth, before fracture, of the resulting cup, together with its regularity and smoothness, being a measure of the quality. Excessive surface roughening indicates a coarse grain size ; while the development of unidirectional cracks or of "ears" round the edges are indications of preferred orientation (q.v.).

Curie Point. The magnetic change p. (A_c) at about 770°C. , at which α -iron, on heating, instead of remaining strongly magnetic, becomes only feebly so. The reverse change is exhibited on cooling.

Cut. In Powder Metallurgy, that portion of a powder sample which lies between two stated particle sizes or two screen-mesh sizes (A.S.M. Defn.).

Cyaniding. The superficial hardening of a steel part, or a portion of it, by heating at a suitable temperature in contact with a cyanide salt, followed by quenching.

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Damascene Steel. A high-grade crucible cast s., containing typically about 1.5 per cent. of carbon, therefore hyper-eutectoid, cooled very slowly in the crucible from a high temperature in the furnace, forged at a temperature below the critical range, and quenched and tempered within definite limits of temperature. In spite of its high carbon content, and the free cementite it must thus contain, D.s. is very malleable and flexible, this being obtained by the complete spheroidization of the cementite by the forging and heat treatment. The ground mass consists sometimes of divorced pearlite, and at other times of troostite, depending upon the final heat treatment of the s. The slow cooling in the furnace leads to the development of a coarse grain growth, which is altered by working so as to give rise to an irregular wavy or motley and highly decorative "watering", or macrostructure, characteristic of this material.

Damping Capacity. A measure of the ability of a material, when subjected to high vibrational stresses, to convert the applied energy into heat, thus damping out by internal losses the vibrations set up by the periodic stresses. The d.c. is thus supplementary to the fatigue value. The term "damping"—as applied to metals in torsion—was apparently introduced by Föppl (*Verein Deutscher Eisenhüttenleute*, 1923, *Werkstoff Bericht* No. 36), who defined it as "the amount of work dissipated as heat by a unit volume of a material during a complete reversed cycle of unit stress"—in other words, the ratio of the loss of energy per cycle to the maximum energy of that cycle—and expressed it as "specific damping capacity", P per cent. This property has been variously termed "internal friction" (Kimball and Lovell, *Trans. Amer. Soc. of Mech. Eng.*, 1926, vol. 48, p. 479), "mechanical hysteresis loss" (Shannon, *Proc. Inst. Mech. Eng.*, 1935, vol. 131, p. 387) and "crackless plasticity" (H. F. Moore, *Iron Age*, 1931, vol. 128, Sept. 10th, pp. 674-7, 721).

Damping Test. A long-period bending or other t. of d. capacity (q.v.).

Dead Annealing. A. for the purpose of leaving the material as soft as possible, *i.e.*, dead soft.

Dead Steel. See Killed S.

Decalescence. The absorption of heat at A_c , and the opposite of recalescence (q.v.).

Decarburizing or Decarburization. (1) As usually understood, the superficial removal of carbon from solid steel, by oxidation during annealing, reheating before quenching, etc. For example, with a carburized surface, the effect, if sufficiently intense, may lead to the production of free ferrite in the case, and soft spots after quenching. Oxidizing atmospheres also cause scaling, when d. is less obvious. With highly stressed parts, d. may predispose to fatigue failure, to which ferrite is much less resistant than pearlite. D. and scaling are avoided by the use of a controlled non-oxidizing atmosphere. (2) Strictly, the term applies also to processes in which d. is intentional, such as the refinement of liquid pig iron to produce wrought iron or steel, or the annealing of whiteheart malleable castings, but d. is not often intended in this sense.

Deep Drawing. A process of drawing sheet and strip of brass, copper, aluminium, low-carbon steel, zinc and zinc alloys, etc., involving a maximum reduction in wall thickness, effected by means of mechanical pressure, much as in the drawing of tube. Metals and alloys for d.d. should have high ductility, be fine-grained and free from directional properties (q.v.). The suitability of a material for d.d. is determined by a cupping test (q.v.), or by various other methods.

Deflectometer. An instrument for measuring the deflection of a cast-iron bar in the transverse test (q.v.). It is usually of multiplying-lever type, the flat base carrying, at one end, a scale along which the lever moves; while the adjusting screw of the lever is arranged under the transverse tool, and is thus not affected by the breaking of the test bar.

Deformation. *See Strain.*

Deformation Axis. In a cold-worked metal, the direction of greatest extension during deformation.

Deformation, Theory of Constant Energy of (Beltrami). A t., advanced as a criterion of failure, which assumes that failure occurs at a constant value of the total elastic strain energy contained in unit volume of the material.

Degrees of Freedom. The number of variable factors, of temperature, of pressure, and of change in the relative proportions of the components (*i.e.*, change in concentration) to which any system may be subject. If any of these factors can be altered with-

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out causing either the disappearance of an existing phase or the appearance of a new phase, the system is said to possess a d. of f. in respect to that factor. See **Phase Rule**.

Delta Iron. Iron free from carbon, or a solid solution of carbon in iron, showing a body-centred cubic form and existing at temperatures between the freezing point (1537°C.) and 1390°C. δ -iron thus shows the same crystal form as α -iron, and it is described as δ only to distinguish it from α -iron below 700°C. , there being no other difference. In the iron-carbon diagram, there are three phase fields containing the δ -constituent: (1) $\delta + \text{liquid field}$, from 1537° to 1490°C. (temperature of peritectic horizontal), the extreme limit of this field (intersection of the liquidus and the peritectic horizontal) occurring at about 0.51 per cent. of carbon. In alloys containing more carbon than this, γ -iron separates directly from the melt. (2) $\delta \text{ field}$, from 1537° to 1390°C. , these limits varying with the carbon content, the extreme limit of this field occurring at about 0.10 per cent. of carbon. Thus, all alloys containing up to 0.10 per cent. of carbon solidify entirely as δ . (3) $\delta + \gamma \text{ field}$, between 1490° and 1390°C. , the limits varying with the composition up to a carbon content of 0.16 per cent. (peritectic point), representing the extreme limit of this field. δ -iron is completely transformed to γ -iron at temperatures between 1490° and 1390°C. , varying with carbon content. δ -iron is not retained on quenching. In alloy steels, the presence of those elements which produce, with iron, systems containing a closed γ -loop (q.v.), extend the δ -field.

Dendrite. A tree- or fern-like skeleton growth commonly found in the crystallization of metals and alloys, and particularly visible on upper surfaces. Crystal growth, starting by the separation, from the liquid metal, of a number of small nuclei, proceeds by the throwing out, from these centres, of a number of arms, with subsidiary arms, at right angles to the first, still others at right angles to the second, and so forth, the exact form depending upon the crystalline type of the metal, cubic, octahedral or other type. Most metals crystallize in the cubic system, the arms extending along the quaternary axes of the cube. Crystallization thus proceeds by the extension in length of the arms and the deposition of further metal upon them, until the intervening spaces are filled. The d. intermesh at their boundaries, their outlines being often very irregular. This dendritic pattern, most evident in cast metal, often persists, although distorted, after cold working, but cold working, annealing or heating through a transformation temperature, all tend to modify or destroy such a structure. *

Dendritic (or Arborescent). (1) *See Dendrite.* (2) In Powder Metallurgy, metal powder particles, usually of electrolytic origin, having the typical "pine-tree" structure (A.S.M. Defn.).

Denseners. Small pieces of iron or other metal, used to promote soundness in castings, being shaped so as to fit against the wood pattern where comparatively heavy masses occur, and usually located in position as the mould is rammed up, and left behind, after the removal of the pattern, so as to form part of the mould face. The metal, having a heat conductivity much greater than that of sand, absorbs heat much more rapidly from the thicker portion, accelerating solidification considerably, and preferably causing the thicker portion to solidify at the same rate as a thinner adjacent portion; when the liability to shrinkage cavities in the heavier portion is much reduced. D. are sometimes incorrectly termed "chills" (q.v.), which, however, serve a quite different purpose.

Density. Mass per unit volume. If c.g.s. units are employed, the d. is identical with the specific gravity (q.v.) referred to water at 4° C. In Powder Metallurgy, *apparent d.* is the weight of a unit volume of powder, usually expressed in grams per c.c. or grams per cu. in., determined by a specific method of loading. *Pressed d.* is the weight of a unit volume of powder which has been pressed into a standard test piece of finished compact at a designated unit pressure. *Tap d.* is the apparent d. of a powder obtained when the volume receptacle is tapped or vibrated during loading (the last three definitions by A.S.M.).

Density Ratio. In Powder Metallurgy, the r. of the apparent d. to the theoretical d. of a solid mass of the powder (A.S.M. Defn.).

Deoxidizers. Substances (either present in, or intentionally added to molten metals or alloys) which either reduce an oxide to metal, or replace a harmful oxide by a harmless one. In steel manufacture, ferro-silicon, ferro-manganese, silico-manganese or aluminium are added finally as d. to convert the soluble ferrous oxide into insoluble oxides which can separate from the molten metal. At an earlier stage in the process, the carbon contained in the melt is a d., reducing ferrous oxide to metal, with the evolution of carbon monoxide gas. Phosphorus is used as a d. in copper and bronze castings, removing soluble copper oxide and giving rise to sound castings. Nickel alloys which in the cast state may contain an embrittling oxide (NiO) are deoxidized by manganese or magnesium.

Depth Effect. In magnetic testing, the property of a powder, due to the shape, size and magnetic permeability of its particles, by

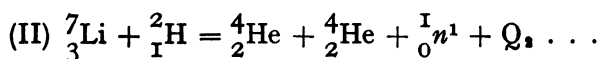
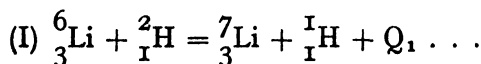
Des

virtue of which it can clearly delimit a defect remote from the surface of the part being tested.

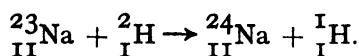
Descaling. The removal of scales and oxide films by various methods, as pickling, sand- or shot-blasting, grinding, etc.

Deseaming. *See* Chipping.

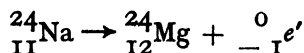
Deuteron, Deuton or Diplon, Symbol ${}^2_1\text{H}$. The nucleus of heavy hydrogen or deuterium, consisting of one neutron and one proton, being thus twice as massive as the proton, the nucleus of ordinary or light hydrogen. It has a mass of 3.3×10^{-24} gm., and a charge of 4.77×10^{-10} e.s.u. or 1.59×10^{-20} e.m.u. Its binding energy is somewhat under 1 million electron volts and its greater mass makes it twice as effective as the proton in atomic bombardment. Its effect on the two isotopes of lithium is as follows.



In the first, the heavier isotope of lithium is produced from the lighter, while the d. disappears and a proton appears. In the second, two α -particles and a neutron result. Similarly, the reaction between ${}^{10}_5\text{B}$ and a d. is the same as that between ${}^{11}_5\text{B}$ and a proton, three α -particles being set free in each case. If sodium is bombarded with d., a radioactive form of sodium is produced by the reaction :



The radio-sodium returns to magnesium as follows :



emitting in the process electrons and γ -rays of energies 1.5, 2 and 3 million volts, the activity decaying by one-half in each successive 16 hours.

Dezincification. In the corrosion of brass, usually by sea water, the apparently preferential removal of zinc, so that the whole or part of the copper appears to be left in the metallic state. The coppery area may be confined to spots, which may extend greatly in depth ("plug d."); or may cover, only superficially, a considerable portion of the surface ("layer d."). The effect is probably due to a complete solution of the brass, followed by the re-deposition of copper.

Die

Dialysis. A process based on the difficulty with which colloidal particles pass through a parchment or other membrane. If a liquid containing a crystalloid in solution, and a colloid in suspension, is put into a vessel whose walls are composed partly of parchment, the crystalloid will readily diffuse through, and, with sufficient changes of water, will finally be removed entirely, the colloid, however, being largely retained by the parchment.

Diamond Pyramid Hardness Test. An indentation test similar in principle to the Brinell test, but using a much smaller diamond indenter, usually a square pyramid with an angle between opposite faces of 136° . Unlike the ball, there is no appreciable deformation of this diamond under the loads employed, so that the hardness number is almost independent of the load. While the upper Brinell limit for ball testing is about 700, hardnesses very much greater can be measured with the diamond, which also gives an impression so small as to make this a non-destructive test. As defined by B.S.S. No. 427—1931, the D.P.H. number is the quotient of the applied load divided by the pyramidal area of the impression, and is given by the formula :

$$H_D = \frac{2P \sin \frac{\theta}{2}}{d^2}$$

where P is the load in kilograms, d the diagonal of the impression in mm., θ the angle between each pair of opposite faces of the pyramidal diamond, and H_D the D.P.H. number. The best-known D.P.H. machines are the Vickers P.H. testing machine and the Firth Hardometer.

Die. (1) A stamp used for impressing or shaping metal, as in the minting of coins or in drop-forging (q.v.). (2) The metal mould used in die-casting (q.v.). (3) In Powder Metallurgy, the part or parts making up the confining form in which a powder is pressed. A *segment die* or *split die* is a die made of parts which can be separated for the ready removal of the compact (A.S.M. Defn.).

Die Casting. The c. of alloys in permanent metal moulds or dies, whereby c. of accurate dimensions, good surface finish and often of complicated shape can readily be produced ; while inserts are often located in the mould so as to constitute part of the c. There are two varieties, gravity d.c. and pressure d.c. In the first, the metal is poured into the mould by the action of gravity, the methods being largely manual, as those of ordinary foundry practice. In the second, a c. machine is used, by means of which the metal, in a liquid or pasty condition, is forced into the mould under pressure, which

Die

may vary from 50 lb. to 5 tons per sq. in., or even more, according to the type of plant employed, the methods being very largely automatic. It should be noted that, in the U.S.A., d.c. denotes only pressure d.c., gravity d.c. being described as "permanent mould casting". In gravity d.c., an accuracy in dimensions of some 0.005 in. per in. can be obtained; in pressure d.c., of 0.001–0.002 in. per in. A batch of 500 can be economically produced by gravity d.c.; while a quantity of 5000 may be required in pressure d.c., which, however, can be a very cheap method for making large numbers of suitable c. Alloys of low melting point are most suitable for d.c.

Die Insert. (1) *See D. Casting.* (2) In Powder Metallurgy, a replaceable liner for a die (A.S.M. Defn.).

Die Set. In Powder Metallurgy, the parts of a press that hold and locate the die in proper relation to the punches (A.S.M. Defn.).

Differential Heating. A heating process by which the temperature varies throughout the object being heated, so that on cooling different portions may have such different physical properties as may be desired. (Prop. Std. Defn., A.S.T.M., 1942.)

Differential Quenching. A quenching process by which only certain desired portions of the object are quenched and hardened. (Prop. Std. Defn., A.S.T.M., 1942.)

Diffusion. In gases, the passage of one into another when there is free communication between the two; when, if sufficient time is allowed, the mixture will become uniform throughout. In liquids or solids, the spreading of a constituent in solution by movement of its atoms from a region of high to one of low concentration of the constituent, so that it tends to become evenly dispersed. D. occurs more readily at higher temperature. An important industrial application is carburizing (q.v.). In Powder Metallurgy, solid d. in the intimate mixture of metal powder particles—occurring at temperatures below the melting point of any of the constituents—may give rise to a homogeneous mass resembling a wrought material of the same composition.

Dilatometry. The study of volume changes in the solid state, such as usually attend a transformation, d. thus affording a valuable means of investigating alloy systems. The instrument used is known as a dilatometer, of which there are a number of types.

Diplon. *See Deuteron.*

Directional Properties. In a solid metallic article, the variation of strength, ductility and other properties in different directions. Thus the hot working of a steel ingot to produce a rolled bar leads to a longitudinal elongation of dendrites, slag inclusions, regions in which phosphorus is segregated, etc., the general result being to increase ductility and notch-value in the direction of working, at the expense of corresponding reductions transversely to that direction. Again, annealing after severe cold working may lead to the development of a preferred orientation (q.v.), which becomes evident on further cold working, the material varying in ductility in different regions.

Discard. *See* Crop.

Disintegration. (1) The decomposition of a radioactive element to give rise to a different element, the process being repeated until a stable end-product, which is not radioactive, is reached (*see* Radioactivity and Transmutation of Elements). (2) In Powder Metallurgy, pulverization (q.v.).

Dispersion Hardening. *See* Age-Hardening.

Dissociation. If a compound is split up into simpler constituents when the physical conditions (temperature, pressure, etc.) change, but the products of decomposition re-combine when the original conditions are restored, the process of decomposition is known as d. In solutions, d. is the splitting up of a compound into atoms, or groups of atoms, termed *ions*, associated with positive and negative electrical charges, respectively. The degree of d. increases with the dilution of the solute.

Dissolved Carbon. Carbon in solution in either the liquid or solid state (A.S.M. Defn.).

Distinctness. In magnetic testing, the readiness with which the powder, either dry or in liquid suspension, can be detected on the surface of the part being tested.

Distortion. An alteration from the usual or ideal shape, resulting, for example, from unequal cooling of a casting, quenching a mass of unequal section, and so forth.

Divorced Cementite. *See* Spheroidal Cementite.

Divorced Pearlite (Granular P., Globular P., Spheroidal P. or Spheroidite). A product of breakdown of this duplex lamellar

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constituent, upon which the strength and notch-value of mild steel much depend. It results particularly from cold working followed by annealing at temperatures a little below the Ac_1 point, especially between 520° and 650° C.; but also by annealing in the same temperature range without previous cold working. The ferrite constituent is absorbed into the surrounding free ferrite, and the lamellæ of cementite coalesce or "ball-up", by the effect of surface tension, into rounded globules, which have little reinforcing effect upon the ferrite, the notch-value, for example, being greatly reduced. Steel so treated is much less resistant than normal steel to plastic deformation. It should be noted that, since p. is always lamellar, p. which has become thus disintegrated should no longer be described as p., and the term spheroidite is more suitable.

Double-Refined Iron. Iron to be classed as double refined shall be all new wrought iron, which shall be first rolled into muck bars. These bars shall then be twice piled and re-rolled. All iron shall be free from steel and from foreign scrap. The manufacturer may use his own mill products of at least equal quality, but only in the first piling. In the final piling all bars shall be of the full length of the pile. (A.S.T.M. Stds., A81—33.)

Double Refining. A treatment used in case-hardening (q.v.), involving reheating and quenching at two temperatures, the first a little above Ac_3 , to refine the core; and the second a little above Ac_1 , to refine and harden the case.

Double Shear Steel. See Shear Steel.

Dozzler. A hollow fireclay cylinder placed on top of an ingot mould, to provide a reservoir of liquid steel, so that the solidifying ingot is free from pipe (q.v.).

Draw. See Shrinkage Cavity.

Drawing. (1) Sometimes "d. the temper", or "d. back", synonymous with *Tempering*, which, however, is preferable, and should be referred to. (2) In the solidification of castings, the production of shrinkage cavities by reason of improper design, insufficient feeding, too low a casting temperature, etc. (3) In the mechanical working of metals, the production of bar, rod or wire in the cold by d. through a tapered hole in a draw-plate, so as to reduce the diameter and increase the length. Seamless tube is produced by d. the tube through the die by various methods, e.g., (a) without a mandrel (sinking); (b) over a plug positioned in relation to the die (plug d.); or (c) over a moving mandrel (mandrel d.). Owing to the

hardening effect of the cold work, only a limited amount of work can be done in each draw, the material then requiring to be annealed before further work can be done.

Drawing Down. Reducing the cross-section and increasing the length of an article, usually by hot working, as forging or rolling.

Drifting Test. *See* **Bulging T.**

Drop-Forging or Stamping. A process of forging by means of two dies, a stationary one fixed to the anvil block, and a moving one attached to the top. The dies are recessed so that together they make up the shape of the complete article, the identity of dimensions of a large number of parts which is thus ensured compensating for the heavy first cost of tooling the dies. For simple parts, one pair of dies may be sufficient; but, for more complicated ones, two or more pairs may be required, for roughing and finishing, respectively. The parts thus produced are also known as d.-f., or s.

Drop Test. A shock t. of a complete part performed by allowing this to d. from a specified height on to a specified base, without fracturing. Thus, a locomotive tyre is allowed to d. freely, in a running position, from a height varying with the diameter of the tyre (*e.g.*, 5 ft. for a tyre of internal diameter up to $3\frac{1}{2}$ ft.) on to a rail fastened to an iron block of weight not less than 2 tons. The tyre is then turned through 90° and dropped a second time. Such tests are also applied to steel castings and other parts. The somewhat similar falling-weight t. (q.v.) is also known as a d.t., particularly in the U.S.A., but each of these terms should be reserved for the t. it more specifically describes.

Dross. Impurities separating to the surface of molten metal, and usually removed by skimming. *See also* **Deoxidizers, Flux, Slag**, etc.

Dry Cyaniding. A process, applied to iron and steel parts, and carried out in a continuous muffle furnace, of continuous gas carburizing and nitriding, at temperatures between 1150° and 1550° F. (*c.* 625° – 850° C.), to produce a surface layer rich in carbon and nitrogen, which is finally hardened by oil quenching.

Ductility. The quality possessed by materials which show considerable plastic deformation before breaking. D. is measured by the percentage elongation and reduction of area, before fracture, in a tensile test; or by the angular deflection before fracture in a bend test. The quality of toughness (q.v.) is sometimes similarly

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defined, but this term should be reserved to describe a different quality.

Duplexing. A combination of two steel-making processes, involving the partial refining of pig iron in an acid Bessemer converter, the Bessemer-blown metal being then transferred while molten to a basic open-hearth furnace for final treatment. The silicon, manganese and carbon of the pig are rapidly removed in the converter, leaving only sulphur and phosphorus to be removed by the O.H. process. Steel can thus be produced in about half the time required by the basic open-hearth process, used alone. D. is particularly suitable for the refining of pig iron which is high in phosphorus (over 1 per cent.), but too low for the basic Bessemer process, requiring at least 2 per cent. *Cf.* **Triplexing.**

Durville Process. A casting method avoiding turbulent flow of the metal; therefore particularly useful for alloys (*e.g.*, aluminium bronze) having an oxide film on the surface when molten. This must be kept on the surface when pouring, for its incorporation with the metal may lead to serious embrittlement. In the D.p., the ladle and mould constitute what is in effect an integral part of the same unit; so that, when this is gradually tilted, the molten metal flows from one to the other with little or no break in the surface film.

Dust. In Powder Metallurgy, the portion of a powder sample which passes a 325-mesh screen (A.S.M. Defn.).

E

Ears. (1) In deep drawing and pressing, the wavy projections on the edges of the article, due to variations in the mechanical quality of the material in different directions ; which, in turn, may be due to the existence of a preferred orientation after annealing ; to undue variation in composition, or to segregation of non-metallic inclusions. (2) A somewhat similar effect produced in rolling (*see Edging Pass*).

Edging Pass. In the rolling of plate, a vertical p. applied either intermittently during the process, or at the end of the same, to ensure correct width, and prevent " fish-tailing " (the production of " ears " at the edges).

Efficiency Ratio. *See* **Endurance Ratio.**

Elastic Hysteresis. In a load-extension diagram plotted also on unloading, the lagging of the strain decrements behind the load decrements, so that the curve is not exactly re-traced, but a small area is enclosed between the two curves.

Elastic Limit (Primitive). The maximum static tensile stress which a material is capable of sustaining without any visible permanent extension remaining after the complete release of the force. *See also* **Elastic Limits (natural)**.

Elastic Limits (natural). The maximum stresses which, when repeated indefinitely, a material is capable of sustaining without a visible permanent set being caused. *See also* **Elastic Limit (Primitive)**.

Elastic Modulus (Modulus of Elasticity or Coefficient of Elasticity). The ratio, within the elastic limit of the material, of stress to corresponding strain, expressed in dynes per sq. cm., kilograms per sq. mm. or lb. per sq. in. The strain may be a change of length (Young's M., Stretch M. or M. of Longitudinal Extensibility) ; a twist or shear (M. of Rigidity, Shear M. or M. of Torsion) or a change of volume (Bulk M.). The last is the ratio of longitudinal stress, applied to all six faces of a cube, to the change of volume. For most metals, the e.m. in tension is almost the same as the e.m. in compression, the e.m. in shear being smaller.

Elastic Recovery. The immediate effect of applying to steel a

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stress beyond the initial e. limit is to lower this value, so that the material can then be plastically deformed by very small tensile or compressive stresses. After a period at room temperature, or a shorter period of heating between 100° and 300° C., the e. limit increases to almost the value of the maximum overstress applied. This process is known as e.r., and is often accompanied by creep leading to a reduction in length—a process sometimes termed *afterworking*.

Elasticity. That property of a material by virtue of which the strain disappears completely when the stress is removed. Steels and many other materials are imperfectly elastic, in that, when subjected to a gradually increasing load, the extension is elastic at first, but becomes partly plastic when the load exceeds a certain value, that of the elastic limit (q.v.).

Electric Furnaces. F. used in the melting and refining of metals and alloys, for which the necessary heat is furnished by some type of resistance to an e. current. The chief types are : (1) *Direct Arc F.*, in which the arc is formed between two or more electrodes and the charge, with which the electrodes may be in actual contact, though they are usually separated by a small space over which an arc is maintained. D.a.f. are of high thermal efficiency, and the Héroult f., in which the bulk of e. steel is made, is of this type ; which has, however, disadvantages when working with comparatively volatile metals, because of the intense superheating of the metal under the arcs. (2) *Indirect Arc F.*, in which the heat is obtained by the generation of an arc between two electrodes placed so high above the bath as to heat it only by radiation. They are of lower thermal efficiency than those of d.a. type ; but, because of the reduced risk of overheating, are more suitable for non-ferrous melting. (3) *Induction F.*, in which no electrodes are used, the metal bath being a complete secondary circuit which is heated by the resistance offered to the alternating current induced from the primary circuit. I.f. are of two types : (a) low-frequency, used in non-ferrous melting ; and (b) high-frequency, used for special steels, nickel and high-temperature alloys in general. A familiar low-frequency i.f. embodies a single-turn secondary transformer, with a channel of liquid metal—carried down in a loop below the main f. chamber—forming the secondary winding. The molten metal in the loop is rapidly heated by the induced current, so as to cause vigorous circulation in the bath above. The loop must be kept completely full when metal is poured from the furnace ; and the metal in it must be kept completely molten, by supplying a small stand-by current for this purpose, at times when the furnace is not melting, such f. being therefore more suitable for melting an alloy of one composition

continuously. (b) In a typical example of the second type of i.f., the heat is developed only in the metal itself, by means of "eddy currents" induced in it by a comparatively cold copper coil surrounding the crucible and carrying a heavy high-frequency current. The spiral inductor coil is wound on a mica or silica sheath fitting over the crucible, the narrow intermediate space being filled with zirconite. There is a very steep temperature gradient between the outside of the crucible and the molten metal, the rapid circulation of which promotes thorough mixing. I.f. are of high thermal efficiency. (4) *Resistance F.*, in which the heat is generated by the resistance of a special refractory trough and then transferred to the charge by direct radiation; or by indirect radiation from the walls or roof. The resistance may alternatively be in the bottom of the f., or the f. may itself be the resistor. Some designs embody more than one of these principles.

Electric Steel. S. refined in an e. furnace, irrespective of process. The principles of refining are the same as for the more usual O.H. process (q.v.). Electricity is, however, a costly fuel, and the melting of old stock or the preliminary refining of ordinary s. in an e. furnace is less economical; so that the e. furnace, usually the Héroult arc furnace, is often employed, as in duplexing and triplexing (q.v.), for the final refining of s. which has already been partly processed. Such furnaces may have either an acid or basic lining, the first type being used more generally for making castings and the second for ingots. S. so refined, although more expensive, is a high-quality product, having a greater freedom from inclusions and being both more ductile and more shock-resisting at low temperatures than s. made by any other process. Basic e. arc furnaces are used for the production of carbon tool s., alloy structural s., heat- and corrosion-resisting s. and high-speed tool s. For special s., the high-frequency induction furnace is often employed to replace the older crucible. An acid lining is used for high-speed and most alloy s.; both acid and basic linings for austenitic chromium-nickel s. and basic linings for manganese s. This furnace is particularly adapted for what is now known as "quality refining", a process in which the molten s. is kept in contact with a suitable slag for a period and at the temperature required to effect the desired improvement in the quality of the metal when finally poured. Here the induction furnace has an advantage over the arc furnace, avoiding the local overheating which is found in the latter.

Electro-Deposition (or Electrochemical Deposition). This term, in its strict sense, is equivalent to electroplating (q.v.); but it is now often used to distinguish the process as used for engineering and cognate purposes rather than for decorative purposes. The two

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processes are fundamentally similar, but there are differences in detail. Thus, electroplating requires usually only a comparatively thin deposit ; while e.-d. deals with thicknesses which are frequently very much greater, and the coating must also often withstand the effects of wear and abrasion. In electroplating, *e.g.*, with chromium, where the deposit is often porous, an undercoat is frequently applied, and the surface of the basis metal must usually be as smooth as possible, this deciding the smoothness of the coating. In e.-d., where the adhesion of the deposited metal must usually be much greater, the surface of the basis metal is frequently roughened, as by anodic etching ; and the coating is usually deposited direct, with no intervening layer. Nickel and chromium are the metals chiefly employed for electro-depositing on steel, the usual purposes being to build up damaged parts and to produce hard surfaces. *See also Chromium-Deposition.*

Electro-Galvanizing. The production of a protective coating of zinc on steel parts by electroplating (q.v.). The usual g. process is hot-dip g. (q.v.), but e.-g. has the advantage of being performed at ordinary temperatures, while a coating of any desired thickness can be obtained. The electrolyte is usually an acid zinc sulphate bath, the anode being of rolled zinc. For small irregularly-recessed parts, an alkaline zinc cyanide bath is more suitable, having greater "throwing power".

Electrochemical Equivalent of an ion is the mass liberated or deposited by the passage of one coulomb of electricity. It is numerically equal to $\frac{1}{96,500}$ of the chemical e.

Electrochemical (or Electromotive) Series. A list of the metals arranged in order of the magnitudes of their single electrode potentials (q.v.), expressed in volts, in solutions of their ions containing 1 gm.-mol. per litre. The order of some of the more common metals is thus : (" Noble " End—positive potential) gold, platinum, silver, mercury, copper, hydrogen, lead, tin, nickel, iron, zinc, manganese, aluminium, magnesium, calcium, sodium (" Base " End—negative potential). A metal later in this s. (*e.g.*, iron) will displace an earlier one (*e.g.*, copper) from its salts. Again, metals later than hydrogen (*e.g.*, zinc) will liberate hydrogen from acids. Other things being equal, the e.s. should also represent the order of relative corrosion resistance, a later or " negative " metal being more corrodible ; but a corrodible metal (*e.g.*, aluminium), which covers itself with a protective film, may be decidedly more resistant than one which from its order in the e.s. should be superior in this respect. Where, however, persistent protective films are not produced, the

e.s. is of considerable practical value. Thus, metals widely separated in the e.s. when in contact in an electrolyte give rise to a stronger current between them, so that the later metal is more rapidly corroded, and the earlier one more protected, this fact affording valuable information as to the probable behaviour of dissimilar metals in contact when immersed in liquids which may serve as electrolytes.

Electrode Potential. The single e.p. of a metal is the voltage of the half-cell formed by the metal in a solution of its ions containing 1 gm.-mol. per litre (the voltage of a complete cell being the algebraic difference of two single voltages, one corresponding with each electrode). A "hydrogen electrode" (consisting of "blackened" platinum saturated with hydrogen at 1 atmosphere pressure) also behaves like a metal electrode in a solution normal in hydrogen ions, and the e.p. of metals is usually expressed on the hydrogen scale, the normal e.p. of hydrogen being taken as an arbitrary zero. The values of the single e.p. of the metals thus vary in sign from positive ("noble" metals) to negative ("base" metals), this order of the metals being known as the Electrochemical or Electromotive Series (q.v.). Since the potential difference between the hydrogen electrode and a normal solution of hydrogen ions is about 0.274 volt, to obtain the absolute potential of a metal electrode, this value must be added to that quoted in the list.

Electrolysis. The passage of an electric current through a solution or a molten salt, so as to direct the charged ions (resulting from the partial or complete dissociation of the dissolved or fused substance) to the appropriate electrode, where their electrical charges are given up. The cations are positively charged and therefore proceed towards the negative electrode or cathode. The anions are negatively charged and proceed towards the positive electrode or anode. The charge being given up, the ions re-form as atoms, and are either liberated as a gas or deposited as a solid at the electrode; or react chemically with the electrode, the solvent, or each other, depending upon the circumstances.

Electrolyte. A liquid or molten solution which partly or completely dissociates into particles, termed *ions*, respectively electrically positive and negative, thus rendering the solution a conductor of electricity.

Electrolytic Deposition. The production of a metal from a solution of its salt by the passage of an electric current (A.S.M. Defn.).

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Electrometallurgy. A term covering a variety of metallurgical processes involving the use of electricity. The chief classes are: (1) the electrolytic processes of extraction, refining, electro-deposition and surface protection of metals and alloys; (2) the electrothermal processes of extraction, refining, melting and heat treatment of the same; (3) the various electrical welding processes.

Electromotive Series. See **Electrochemical Series.**

Electron (or Negatron), Symbol ${}^0_{-1}\text{e}$. A negatively charged sub-atomic particle, with a mass, m , of 0.00055 on the $\text{O}^{16} = 16$ scale, or of 8.8×10^{-28} gm., a radius of about 2×10^{-13} cm., and a charge, e , of 4.77×10^{-10} e.s.u., or 1.59×10^{-20} e.m.u. The ratio of the specific electronic charge to the mass of an e. is constant for all e., and is experimentally 1.758×10^7 e.m.u./gm. Beta particles are high-velocity e.; cathode particles are low-velocity e. If m_0 = mass of the e. at low speeds, and m = mass at any other speed, then $m/m_0 = 1/\sqrt{1 - \beta^2}$, where β is derived from the equation: β = Velocity of e./Velocity of light. The e. possesses a quantum spin of one-half a quantum unit. Regarded as waves, e. have a w.l. of h/mv , where h is Planck's Constant, m is the mass and v the velocity in c.g.s. units. The energy of the e. = 2.65×10^6 electron volts (max.). As a nuclear constituent, the e. is combined with a proton to form a neutron. When an e. is emitted from a nucleus, it is conjectured that it is created at the moment of emission, so that a neutron disappears from one state and a proton appears in another. Free or extra-nuclear e., arranged in "shells" round the nucleus, regulate the chemical and spectroscopic properties of the particular element.

Electron Compounds. Intermetallic c. which do not conform to the ordinary valency law, but are characterized by a similar ratio of valency e. to atoms, the term connoting that the phase pattern depends upon the relative numbers of these. Thus, the c., CuZn , has 3 valency e. (one from the copper and two from the zinc atom) and 2 atoms, giving the ratio 3 : 2; which is also found with the c., Cu_3Al , where there are 6 valency e. (three from the aluminium and one from each copper atom) and 4 atoms. There are three main classes of e.c.: (1) E.: Atom Ratio = 3 : 2 (Body-Centred Cubic Structure), e.g., CuZn , Cu_3Al , Cu_3Sn , FeAl ; (2) E.: Atom Ratio = 21 : 13 ("γ-Brass" Structure), e.g., $\text{Cu}_7\text{Zn}_{11}$, Cu_3Al_4 , $\text{Cu}_{11}\text{Sn}_3$, $\text{Fe}_7\text{Zn}_{11}$; (3) E.: Atom Ratio = 7 : 4 (Close-Packed Hexagonal Structure), e.g., CuZn_3 , Cu_3Sn , Cu_3Si .

Electronegative. Carrying a negative charge, as with the ions of hydroxyl, chlorine, etc., which pass to the anode of an electrolytic cell.

Electronic Structure. The extra-nuclear electrons are arranged round the nucleus of the atom in a series of rings or "shells". That nearest the nucleus, composed of electrons with the highest energy level or ionizing potential (q.v.), is known as the *K*-shell, the next as the *L*-shell, and so on. Each shell contains electrons with the same principal quantum number, n ; and each shell is fully occupied by electrons—being then said to be *closed*—when it contains $2n^2$, viz., 2, 8, 18 or 32 electrons. Within the single shell, the electrons having the same subsidiary quantum number, l , are known as a sub-group, designated by the letters *s* (sharp), *p* (principal), *d* (diffuse) and *f* (fundamental), terms describing the various series of optical spectra before their mode of origin was understood, further sub-groups being designated by *g*, *h*, etc. In each complete sub-group, the number of electrons is $4l + 2$, i.e., 2, 6, 10 and 14, for $l = 0, 1, 2$ and 3, respectively, a relation which is consistent with Pauli's Exclusion Principle (q.v.). The method by which the successive electron shells are built up is shown in the table, covering three different values of the

ARRANGEMENT OF ELECTRONS IN GROUPS AND SUB-GROUPS

| | | | | | | | | | | | | | | | | |
|---|----------|----------|------------|---|---|---|----------|------------|---|----|------------|---|---|---|--|--|
| Group or Shell . . . | <i>K</i> | <i>L</i> | | | | | <i>M</i> | | | | | | | | | |
| Principal Quantum Number, <i>n</i> . . . | 1 | 2 | | | | | 3 | | | | | | | | | |
| Designation of Sub-Group . . . | 1s | 2s | 2 <i>p</i> | | | | 3s | 3 <i>p</i> | | | 3 <i>d</i> | | | | | |
| Subsidiary Quantum Number, <i>l</i> . . . | 0 | 0 | 1 | | | | 0 | 1 | | | 2 | | | | | |
| Magnetic Quantum Number, <i>m</i> . . . | 0 | 0 | -1 | 0 | 1 | 0 | -1 | 0 | 1 | -2 | -1 | 0 | 1 | 2 | | |
| Number of Levels in Sub-Groups . . . | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | | |
| Total Number of Levels . . . | 2 | 8 | | | | | 18. | | | | | | | | | |

principal quantum number, and those values only of subsidiary and magnetic quantum numbers that apply in these cases. It will be appreciated that the use of the fourth quantum number does not affect the position of an electron, but only its spin.

The method by which the successive electron shells are built up

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may be illustrated by some typical examples, those of the alkali metals, whose electronic arrangements are shown in the second table. Lithium has 3 electrons, 2 closing the *K*-shell, so that the

ATOMIC STRUCTURES OF ALKALI METALS

| Principal Quantum Number, <i>n</i> . . . | 1 | 2 | 3 | 4 | 5 | 6 |
|--|----------|----------|----------|-------------|----------|----------|
| Group or Shell . . . | <i>K</i> | <i>L</i> | <i>M</i> | <i>N</i> | <i>O</i> | <i>P</i> |
| Sub-Group . . . | 1s | 2s 2p | 3s 3p 3d | 4s 4p 4d 4f | 5s 5p 5d | 6s 6p 6d |
| Element and Atomic Number | | | | | | |
| Li, 3 | 2 | 1 | | | | |
| Na, 11 | 2 | 2 6 | 1 | | | |
| K, 19 | 2 | 2 6 | 2 6 | 1 | | |
| Rb, 37 | 2 | 2 6 | 2 6 10 | 2 6 | 1 | |
| Cs, 55 | 2 | 2 6 | 2 6 10 | 2 6 10 | 2 6 | 1 |

third must go to the first sub-group (2s) in the *L*-shell. Sodium has 11 electrons, 2 closing the *K* and 8 the *L*-shell, so that the eleventh is in the *M*-shell. Potassium, with 19 electrons, shows the *K*- and *L*-shells closed, and 8 electrons in the *M*-shell (only the *s* and *p* sub-groups being closed), as compared with a possible 18. A shell of 8 electrons constitutes a very stable grouping, however, and electrons can occupy the *d* sub-group only with higher nuclear charges. The remaining electron is thus in the *N*-shell. A similar arrangement is seen with rubidium and caesium, the odd electron in each case going to a further shell. With caesium, the *4f* sub-group, with room for 14 electrons, remains empty, beginning to fill up only with higher nuclear charges. All the alkali metals thus have a single outer valency electron (q.v.) external to a stable grouping, a fact which explains both their resemblance to each other, and their reactivity, a solitary electron in a shell having low ionizing potential (q.v.), and being readily removed from the atom.

Electronic Theory of Valency. According to this t., v. arises from the electrons in the outer shell of the atom (the v. group), because these only are so loosely bound to the nucleus as to be affected by energy changes on the scale found in ordinary chemical reactions; while, also, it is the outer electrons which must be con-

cerned when two atoms combine to form a molecule. Maximum stability is found when there are 8 electrons in the outer shell of the atom, and combination between two atoms becomes theoretically possible if there are not 8 electrons in the outer shell of either atom. The effect of chemical combination is to give rise to an outer shell containing 8 electrons. There are three types of v., as follows : (1) *Electrovalency*, in polar compounds, in which the stable grouping of 8 electrons in the outer shell is effected by a transfer of electrons from one atom to another. Thus the electronic structure (q.v.) of the sodium atom is 2 : 8 : 1, and that of the chlorine atom 2 : 8 : 7. By the transfer of an electron from the sodium to the chlorine atom, each has now a complete or closed outer shell or octet. The sodium atom, having lost an electron, has become positively charged ; and the chlorine atom, having gained an electron, has become negatively charged, these oppositely-charged particles or *ions*, each with a separate existence, being kept in proximity to each other by the electrostatic force of mutual attraction between them. Electrovalency is negative when electrons must be added for this purpose, and positive when electrons must be given up. Compounds showing electrovalency constitute the class known as electrolytes (q.v.). (2) *Covalency*, in non-polar compounds (not ionized), in which a molecule is formed by the union of two atoms by the sharing of pairs of electrons—as distinct from their transfer—so that each atom has six unshared and two shared electrons to complete the stable outer shell. The shared pair unites the atoms, and constitutes a single “ v. bond ”. This method of combination is known as a *Covalent* or *homopolar linkage*, which necessitates that two electrons are held in common between the two atoms. There are also, exceptionally, forms of v. intermediate between these two forms, in which there is a partial transfer of electrons between the two atoms. (3) *Co-ordinate Linkage* (or *Semi-Polar Double Bond*), in which there is a sharing of two electrons, both supplied by *one* of the atoms.

Electroplating, Plating or Electro-Deposition. The electrolytic deposition of one metal on another, for decorative and protective purposes. The part to be plated is the cathode and the metal to be deposited the anode in an electrolytic cell, these electrodes being connected, respectively, to the positive and negative terminals of a suitable source of current. The electrolyte is usually an aqueous solution of a salt of the metal to be deposited, frequently a double cyanide. On completing the circuit, and under suitable conditions (concentration of electrolyte, current density, temperature, cleanliness of surface to be plated, etc.), metal is transferred from the anode to the cathode. The acidic radical liberated at the anode dissolves further metal, preventing the weakening of the solution that would otherwise occur. The thickness deposited depends upon the

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current density, the efficiency of the bath, and the time taken. Some alloys may also be plated, as brass, to match solid brass. It should be noted that the term, electro-deposition (q.v.), is now often applied in a particular sense.

Electropolishing. A process of polishing metals and alloys by an electrochemical treatment rather than by cutting, tumbling, buffing or burnishing. The process is the reverse of that used in electroplating. While first employed as a means of polishing samples for microscopic examination, the process has now invaded the industrial polishing field.

Electropositive. Carrying a positive charge, as with the ions of metal or acidic hydrogen which pass to the cathode of an electrolytic cell.

Electrovalency. See **Electronic Theory of Valency**.

Element (or Chemical Element). A chemically pure substance which cannot be further disintegrated by ordinary chemical means. A substance all the atoms of which have the same atomic number. E. can be further disintegrated by extra-chemical means. See **Atom**, **Transmutation of Elements**, etc.

Elongation. The amount of permanent extension, before fracture, in a tensile test piece of standard dimensions; usually expressed as a percentage of the original gauge length. This e. is the sum of two separate and distinct e., one a general extension over the whole of the parallel part of the test piece, gradually increasing with load, and varying directly with the gauge length; the other, a local extension at the position of fracture, varying with the cross-sectional area, but independent of the gauge length. The effect of this local extension upon the extension as a whole must be greater as the gauge length becomes shorter. Therefore, to ensure that the same e. value is obtained from test pieces of varying sizes, these must be geometrically similar. The dimensions of British standard tensile test pieces comply with the formula, $L = 4\sqrt[3]{A}$, where L is the acting length and A the cross-sectional area. Other formulæ, however, are also employed.

Embrittlement. The development of brittleness in a material which has not previously shown this effect. E. may be shown by actual failure in service (e.g., season cracking); or by a reduction in ductility and notch value, often associated with an increase in strength and hardness. E. may be caused during the process of manufacture (e.g., by excessive cold-working, by strain-ageing,

End

tempering or pickling) ; by a combination of unsatisfactory manufacture and the effects of particular service conditions (caustic e., season cracking, weld decay) ; or by the service conditions alone ("burning" of steel). *See also* **Caustic E., Pickling Brittleness, Temper Brittleness, Strain-Age-Hardening, etc.**

Emission Spectrum. *See* **S.**

Emissivity (Emissive Power or Black Body Coefficient). The ratio of the radiating power of a body to that of a true "black body" under identical conditions, determined in unit time on unit surface area for unit difference of temperature between the surface and surrounding bodies. In c.g.s. units, *e.* is given in ergs per second per sq. cm. with the radiating surface at 1° absolute and the surroundings at absolute zero. The *e.* of a surface exactly equals its absorptivity (*q.v.*), *i.e.*, a poor absorber is a poor reflector.

Ending. (1) Described also as "topping", breaking off the top end of an ingot at the mouth of the mould, to observe pipes or other defects. (2) Breaking off the ends of bars, to detect cracks or other defects, and as a check on quality.

Endurance. That quality of a material by virtue of which it can sustain, for a sufficiently lengthy period, the stresses to which it may be subjected, and any other attendant effects—wear, corrosion, etc.—which may also result from service. The *e.* of a test bar is the number of repetitions of the operating stress cycle which will lead ultimately to failure.

Endurance Limit, Fatigue Limit or Fatigue Range. In fatigue testing, that value of the stress range just insufficient to cause failure of the specimen after the repetition of a sufficiently large number of stress cycles. Since the application of a still greater number of the same stress cycles might lead ultimately to failure, the number of cycles over which the *e.l.* has been determined must obviously be stated. In practice, a figure of 10,000,000 reversals is frequently adopted. If the test piece does not fail during the application of this number of reversals, it is assumed that it will resist failure indefinitely. For all practical purposes, this view is correct ; while variations in the rapidity of stress reversal over wide limits, from a few hundreds up to 5000 per minute, make no appreciable difference in the value determined.

In the presence of corrosive agents, the *e.l.* may be very much reduced, and it seems very doubtful indeed whether there is any true *e.l.*, for failure may occur at very low stresses if the number of cycles

End

is sufficiently great. Quoted figures for e.l. under these conditions are thus only e.l. for the given number of stress cycles.

Endurance Ratio (or Efficiency R.). The ratio between the fatigue limits for reversed stresses, usually reversed bending stresses, and the ultimate strength of the material by the static test. With reversed bending stresses, the average value of this r. is about 0.45 for steels.

Endurance Testing. *See* Fatigue T.

Energizers. In the carburizing process, materials, usually metal carbonates, as those of barium and sodium, incorporated to the extent of 5–20 per cent. with the carbon base of the carburizing compound, in order to accelerate the absorption of carbon by the steel part. E. are generally considered to act as catalysts in the $C:CO_2:C$ reaction, to increase the amount of carbon monoxide liberated, this gas being that chiefly responsible for the carburizing effect. According to another view, carbon monoxide is catalytically decomposed by the carbonate, to give rise to a finely-divided and very reactive form of carbon on the steel.

Energy, Atomic. *See* Atomic E.

Equi-axed Crystals. C. which have dimensions approximately equal in all directions. Such c. are found, with random orientation, in the interior of cast metals which have not been strained. They are also found in strained metals after annealing, when the orientation may not be random; but may be preferred (q.v.).

Equilibrium (Stable E.). The condition of a material which is in a state of complete physico-chemical balance, *i.e.*, when any change of state, which leads to no alteration of its entropy, does not reduce its energy. A condition in which, so long as a metal or alloy remains at a particular temperature, there is no tendency for any change of state or structure to occur. Imperfect E. is e. which has only partially been obtained, as when the rate of cooling of an alloy, although not sufficiently rapid to cause the suppression or suspension of a phase, is yet rapid enough to hinder diffusion, and thus retard the obtaining of true e. *See also* Metastable E.

Equilibrium Diagram. A diagram, constructed from thermal and other data, for all combinations of the two or more constituents of the particular alloy system, showing the phases which exist in the system at any composition and any temperature (provided the alloy is in equilibrium). Since the various phases are each associated with

particular mechanical and other properties, a knowledge of the e.d. is fundamental to the study of mechanical and other properties of alloys in general.

Erosion. The destruction of metals or alloys by a mechanical agency, as the grinding of iron to a metallic powder. E. may frequently be associated with corrosion, as when cavitation effects—the collapse of vacuum cavities upon metallic surfaces—lead to the removal of a protective surface film, and also prevent its renewal, the metallic surface being thus exposed to continuous attack.

Etch-Figures (Corrosion F., Etching Pits or F.). Minute cavities of geometrical outline, obtained on deeply etching a metallic surface. The form of these is indicative of the crystal system to which the material belongs.

Etchant or Etching Reagent. A substance or reagent used in etching (q.v.), and usually a solution in water, acid or alkali. Etchants consist in general of three classes: (1) those whose etching effect depends primarily upon their content of hydrogen ions; (2) those whose etching effect depends upon their content of hydroxyl ions; (3) those producing a differential staining effect, the chemical nature of which is still often obscure. A violent etchant is one whose action is accompanied by the liberation of gases; a non-violent etchant is one whose action is not accompanied by any liberation of gases, there being merely a direct transfer between the etchant and the sample. An analogous effect is obtained in heat-tinting (q.v.).

Etching. (1) A process of chemical attack upon the polished surface of a metal or alloy, to remove the surface film of altered metal produced in polishing; and, by selective attack upon the various constituents, to develop differences in their colour or appearance, whereby they may be distinguished from each other, and particular features of the structure determined. In general, *Deep E.*, with strong reagents, is used to develop macrostructures; while *Detail-* or *Micro-E.*, using weaker reagents which are sometimes stimulated electrolytically, is used for microstructures. Much depends upon the choice of etchant, and the technique of the operator. See also **Contrast E.** and **Polish Attack.** (2) A means of lettering or otherwise “marking” metal, the part it is not desired to etch being suitably protected from attack.

Eutectic or Eutectic Alloy. Of a series of alloys between two or more metals, that which has the lowest melting point of the series. At this minimum or e. temperature, on cooling, the separating solids—which may be pure metals, solid solutions or metallic compounds—

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are deposited simultaneously from the liquid as an intimate mixture of two or more phases in fixed proportions. E. may be binary, ternary, etc.

Eutectoid. An aggregate fundamentally similar to a eutectic (q.v.), but produced, not in cooling from the liquid, but completely in the solid state. At the minimum and constant temperature in a completely solid system, a similar complex aggregate, of definite composition, is formed. E. may be binary, ternary, etc., and are composed of a continuous phase, together with one or more dispersed phases, which may either be lamellar or granular, according to the rate of cooling.

Eutectoid Steel. Steel containing the eutectoid proportion of carbon, and therefore composed, under conditions of slow cooling, of pearlite only. In carbon steels, the eutectoid contains about 0.85 per cent. of carbon ; but, in the presence of additional elements, such as nickel and chromium, the carbon content of the eutectoid may be considerably reduced.

Exfoliation. The peeling off, or crumbling away, of thin surface layers of sheet, etc., due to excessive cold working (q.v.). *See also Overworking.*

Expansivity. *See Thermal Expansion.*

Extensometer. An instrument capable of measuring accurately the minute elastic extension of a test piece. For steel, this is no more than about 0.0025 to 0.0030 in., on a gauge length of 2 in., and it is still less for other alloys. *See Elastic Modulus, Hooke's Law, etc.*

Extra-Hard. *See Quarter-Hard.*

Extrusion. A process involving the use of a press to force plastic metal through a die of the required shape ; as that of round rod, channel or other section. The press embodies a pre-heated container, into which is charged the cast billet of metal, pre-heated to the appropriate temperature, depending upon its composition, e.g., 100° C. for zinc ; 350° C. for aluminium and its alloys, and 800° C. for brass. One end of the container is closed by the alloy steel or tungsten carbide die, and the other end by a disc or pad, having only a very small clearance in the container. Behind the pad is inserted a plunger head, to which, in the *direct* e. process, pressure can be applied either by a crank mechanism or by means of a pressure cylinder and ram, so as to cause the billet to move along the container, and the plastic metal to be forced through the die at a steady

rate. In the *inverted* e. process, the die is located in a hollow extrusion ram, by means of which it is forced into the billet, which thus does not move along the container, when e. can be performed at a somewhat lower pressure. In the direct process, the whole of the cross-section of the container can be utilized ; but in the inverted process only a fraction of it, the latter for this reason being in lesser use. In the production of tube and pipe, the older method of piercing and drawing is being gradually replaced by e., *e.g.*, a solid billet may first be pierced by a central plunger, which then remains as the mandrel round which the tube is extruded.

Extrusion Defect. A defect, formerly very troublesome, in which about the last quarter of each bar had to be discarded, as containing a sound central core separated by an oxidized layer—part of the original skin of the billet—from the sound exterior material. The cooler outer layer of the billet does not flow so readily as the hotter interior metal, particularly as the operation proceeds ; and, as the central portion flows towards the die, the outer layer is turned inwards and becomes incorporated in the core material, giving rise to the d. in question. By using the inverted method of e., in which the die is pushed back against the billet, the oxidized skin remains at the back of the die, where there is practically no flow ; so that almost the whole of the billet can be extruded without this internal d. being caused.

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Factor of Safety. (a) Usually, the ratio of the ultimate strength of a part to the calculated service stress supported by it. (b) In another use of the term, the yield point, instead of the ultimate stress, may be the criterion. (c) The term sometimes relates the fatigue resistance of the material, under ideal conditions, to the working stress. If the material might locally be faulty, the design of the part unsuitable, or the part subject to vibration, the factor would be increased to cover the local accentuation of normal working stress due to the special condition. (d) In creep tests, it is frequently the practice to base permissible creep stress values upon the results of short-period tests, in which the creep rate does not exceed a small but conveniently measurable value. This rate may be very much greater than could be tolerated in practice for the particular duty. The maximum safe working stress is therefore derived from the test stress by applying a f. of s. of somewhat dubious value.

Faggot. In the manufacture of shear steel (q.v.), the small bars of blister steel which are welded together under the hammer.

Fagoting. In the manufacture of wrought iron, the making of a "fagot" or "box", the bottom and sides of which are formed of muck or scrap bars and the interior of miscellaneous iron scrap or a mixture of iron and steel scrap. (A.S.T.M. Stds., A81—33.)

Falling-Weight Test (sometimes incorrectly termed *Drop Test*, q.v.). A t. in which a given weight is dropped from one or more given heights upon the part being tested. This must be supported as specified, must not fracture, and is often required to show a minimum deflection under the t. For railway tyres, a weight of 1 ton is allowed to fall freely on the tread of the tyre, which is placed in the running position upon a heavy cast-iron anvil, supported by a rigid concrete foundation. On subjecting to successive drops from heights of 10, 15, 20 ft. and upwards, the tyre must deflect to a specified amount, varying with its tensile strength, without fracture. Similar t. are applied to axles and other parts.

Fatigue Failure. The failure of a material, usually of steel, by the repeated application and removal of stresses within the static elastic limit of the material. Stress repetitions which lead ultimately to failure must cause some structural damage to the material, and the term "fatigue failure" is thus a not entirely happy one, for it might be supposed that "fatigued" steel could be restored to its

normal condition by a period of rest ; just as work-hardened steel can be restored by annealing. No treatment, short of re-melting and forging once more, will restore steel which has suffered structural damage as indicated. In practice, a fatigue failure results from the development of a crack from some point of high stress concentration (*see Stress Raisers*), and its gradual progress, with time, across the section, until the remaining sound metal cannot sustain the load, and breaks suddenly. *See also Corrosion Fatigue.*

Fatigue Fracture. A fracture due to failure by fatigue, and characteristically duplex in appearance. The major portion is usually discoloured and smooth, this being the portion over which the spreading crack has slowly developed, the smoothness being due to the continual touching together of the two fractured faces, which may also show lines representing successive crack boundaries ; while a smaller area—often less than 10 per cent. of the total cross-section—shows a comparatively bright, coarse or fibrous fracture, which may be somewhat deformed, however, by the hammering together of the two faces just after parting. F.f. are often of a complex nature, involving the convergence of cracks from several separate origins ; or the divergence of longitudinal into transverse cracks, or *vice versa*.

Fatigue Limit or Fatigue Range. *See Endurance Limit.*

Fatigue Testing (or Endurance T.). In fatigue tests in general, a series of test bars of the same material are subjected in turn to repeated ranges of stress, of diminishing magnitude, until the maximum safe range of stress—*i.e.*, that which does not cause failure of the specimen, even if repeated indefinitely—has been determined. *See also Endurance, Endurance Limit, Endurance Ratio, Wöhler Fatigue Test, etc.*

Ferrite. α -iron, crystallizing in the body-centred cubic form, stable below about 900° C., and resulting from the $\gamma \rightarrow \alpha$ transformation below this temperature. F. is feebly magnetic down to about 780° C. (Curie change point), and then strongly so. It contains practically no carbon, actually a maximum of 0.007 per cent. at ordinary temperatures, and about 0.03 per cent. at 700° C., a proportion, however, which may play an important part in ageing. In commercial steels, f. always contains silicon, phosphorus and manganese in solid solution. It comprises almost exclusively the metallic part of wrought iron ; and it exists in hypo-eutectoid steels as massive or free f. ; and also in the f.-cementite aggregate known as pearlite, than which it is considerably weaker in resisting fatigue and shock stresses, failures from which are confined almost exclusively to the free f. constituent. The term is also applied to the

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α -iron constituent in an alloy steel, which may hold in solution considerable proportions of the alloy elements, when the $\gamma \rightarrow \alpha$ transformation temperature may be considerably affected.

Ferrite Ghost. See Ghost.

Ferro-Alloys. An alloy of iron with a sufficient amount of some element or elements, such as manganese, chromium or vanadium, used as a means of introducing these elements into steel, cast iron, etc. (A.S.M. Defn.).

Ferrous Alloy. An alloy in which iron is the preponderating element.

Fescolizing. An electrolytic process of depositing a layer of metal, usually nickel or chromium, on a steel part, to enhance corrosion- and wear-resistance.

Fibre. A characteristic of certain ductile wrought metals, such as iron and steel, indicating directional properties in the material, and shown by fibrous and woody fractures. F. is due in part to the extension of the crystal grains in the direction of working, and also to the elongation of slag particles and other non-metallic inclusions in the material, being thus particularly accentuated in wrought iron. In steel, f. is more marked when a banded structure is present.

Figure of Merit. A criterion of quality put forward by Rosenhain, requiring minimum values for all qualities of the material, apart from those which appear specifically to apply for the particular duty. The specifying of minimum values for all the important qualities should render the engineer reluctant to accept any material which does not show at least these minimum figures in corresponding tests, even if the material may appear particularly attractive in certain other directions. In using this method, the minimum values should not be fixed unduly high. Further, the refusal to employ materials falling in certain respects below the minimum values should be subject to revision if their reliability for a particular purpose can be demonstrated, either in service or other suitable manner.

Finished Steel. S. which is ready for the market without further treatment, and including sheets, strip, plates, tin plates, shapes, bars and wire. Semi-F. S. requires further treatment before marketing and includes billets, blooms, slabs, sheet bars, wire rods, etc.

Finishing Temperature. The temperature at which hot mechanical working of metal is completed (A.S.M. Defn.).

Fir-Tree Crystal. *See* Dendrite.

Fire-Cracking. The cracking of internally-stressed parts on heating for annealing, owing to the superimposing of heating stresses upon existing stresses, the total exceeding the tensile strength of the material.

"Fish-Tailing". *See* Edging Pass.

Flakes, Snowflakes or Shatter-Cracks. (1) Defects shown on parts of the fractured surfaces of steel tensile test pieces, usually of somewhat circular shape, small surface extent, and with a bright scaly appearance. They are caused by the opening up of local internal fractures produced in the steel when it is cooling from about 400° to 200° F. Their origin is in some dispute, but they are found only when hydrogen is present in the steel. Material showing f. is frequently of low strength and ductility, but the Izod value may not be appreciably affected, unless the crack is very close to the notch. *See* Hair-Line Cracks. (2) In Powder Metallurgy, f. are flat or scale-like metal powder particles whose thickness is very small compared to the other dimensions.

Flame Annealing. A process in which the surface of an iron-base alloy is softened by localized heat applied by the flame of a high-temperature torch. (Prop. Std. Defn., A.S.T.M., 1942.)

Flame-Hardening or Shorterizing. A surface-hardening process applied to steel crankpins, gearwheels, etc., in which local heating to above the upper critical temperature (A_{c_3}) is followed immediately by quenching with a water jet. This is integral with the flame head, the whole being mechanically controlled, so that the angle of, and the distance between, the flame and jet, as well as the speed of travel, can be closely controlled. The material is usually a 0.50-0.55 per cent. carbon, or suitable alloy steel. A Vickers hardness value of 800, equivalent to a Brinell hardness of more than 600, can readily be obtained. The interior of the part is not affected, and the article must be treated so as to obtain the core properties desired, before the f.-h. operation.

Flame Strengthening. The use of the flame-hardening process (q.v.) to obtain a local increase in the fatigue resistance of highly stressed parts.

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Flanging Test. A ductility t. for copper and brass tubes, where a short portion of the tube must stand flanging cold without showing either crack or flaw, until the diameter of the flange measures not less than 40 per cent. more (for copper) or 25 per cent. more (for brass) than the original diameter of the tube. A f.t. is also used for some iron and steel tubes.

Flattening and Doubling-over Test. A ductility t. for copper and brass tubes and pipes, where the material when cold must be amenable to the following procedure without showing either crack or flaw. The t. piece must be flattened down until the interior surfaces of the tube or pipe meet ; and must then be doubled over on itself, *i.e.*, bent through an angle of 180° , the bend being at right angles to the direction of the length of the tube or pipe. The t. is sometimes required to be done at a red heat.

Flow Characteristic. In Powder Metallurgy, the rate at which a metal powder will flow through an orifice in a standard instrument, and/or according to a specified procedure (A.S.M. Defn.).

Flow Lines. Striations produced on etching a ductile material, such as steel, which has been strained plastically ; and caused by the elongation of crystals through cold working. They are due to local electrolytic differences of potential set up by varying degrees of local distortion, and indicate the principal directions in which movement of the material has occurred.

Flowing Power (Fluidity, Liquidity, Running Quality or Life). That quality of a molten metal or alloy which enables it to fill a sand mould of a specified type and size. Its value is determined by employing a horizontal spiral or other test mould, into which the metal is run, when the length of the cavity filled by the metal before solidification is a measure of the f.p. This depends both upon external factors, as the mould material, its facing and temperature and the pouring head and superheat ; and upon internal factors, as the composition, freezing range, thermal properties, surface tension, surface oxide films, gas content and suspended inclusions.

Fluting. (1) The production, on rolling or forming, of a series of localized bends or waves in plate, *e.g.*, tinplate ; instead of a smooth uniform surface. A plate which has been rolled out longer on one side than the other will show f. on the long side when the plate is straightened. (2) The term is sometimes applied to a somewhat similar defect, due specifically, however, to stretcher strains (q.v.).

Flux. A substance added : (1) in the smelting of metals, to

combine with the earthy or other impurities of the ore, so as to produce a fusible slag and thus facilitate the separation of impurities from the reduced metal ; *e.g.*, the use of limestone in the blast furnace to combine with clay as a fusible silicate ; (2) in the refining of metals, for the similar production of a fusible slag ; (3) in the melting of metals, to remove, partly chemically and partly mechanically, the metallic oxides and other impurities which may be present, thus giving rise to cleaner metal, increasing fluidity and reducing the possibility of gas reactions leading to unsoundness in castings ; *e.g.*, the use of borax to remove zinc oxide in brass melting ; (4) in brazing, soldering, tinning and the like, to remove the oxide film and facilitate the union of the deposited and the parent metal ; *e.g.*, the use of zinc chloride ("killed spirits") in tinning. Fluxes must therefore be fusible under the operating conditions, and the melt must be sufficiently liquid to enable the metal to separate readily from them ; while, in brazing and similar operations, they must also be capable of "wetting" the surfaces which are to be joined. Fluxes may be acidic, as quartz or sand ; basic, as limestone or soda ; or neutral, as fluorspar ; their varying suitability depending upon the impurities, original or secondary, associated with the metal or alloy in the purification of which they are to be used.

Forgeability. A measure of the capacity of a material for hot working.

Forging. (1) The process of shaping hot metal by hammering, usually with a steam- or pneumatic hammer. Deformation is thus produced by means of a succession of sudden blows, each of limited and local effect, so that the refinement of the structure of steel produced by hot working (*q.v.*) does not extend to the interior portions of parts of larger section, for which press-f. (*q.v.*) is more suitable. *See also Drop-f.* (2) The article thus produced.

Fracture. The irregular surface shown when a piece of metal is broken. F. are divided into various classes, the descriptions of which vary somewhat with the observer. Some of the usual classes, covering more particularly iron and steel, are as follows : (1) *Crystalline*, usually bright and glittering, failure having developed along the cleavage planes of the individual crystals. Characteristic of brittle materials which have broken without distortion ; and shown by cast iron of more "open" grain. (2) *Fibrous* or *Woody*, usually grey and amorphous, the fibrous character being due to the elongation of the individual crystals, and accentuated by the presence of slag and of a banded structure. Characteristic of inhomogeneous ductile materials, as wrought iron. (3) *Silky*, usually dull in colour but fine in texture, with no apparent evidence of crystalline structure.

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Characteristic of homogeneous ductile materials with a fine structure, as mild steel. (4) *Vitreous*, characteristic of brittle materials of fine structure. (5) *Granular*, the surface of f. tending to follow the intercrystalline boundaries, so that the coarseness or fineness of the structure is a measure of the grain size. Characteristic of cast metals of low ductility. See also *Conchoidal F.*, *Cup F.* and *Fatigue F.*

Fracture Test. Breaking a piece of metal for the purpose of examining the fractured surface to determine the structure or carbon content of the metal or the presence of internal defects (A.S.M. Defn.).

Free-Cutting Quality. The quality by virtue of which metals and alloys are readily machinable. Very ductile metals do not readily shear under the severe stresses generated by the cutting edge of the tool ; but instead drag or flow under them, tending to come away in irregular pieces, so that the work has a very poor finish. If the homogeneity of the ductile metal is broken up by the presence of a suitable dispersed phase in sufficient quantity ; or of inclusions of one kind and another, the turnings part off readily, and the work has a good finish. In mild steel, machinability is promoted by the presence of pearlite (low-carbon steel, containing little pearlite, being often very troublesome in this respect) ; in brasses, by the addition of lead ; in stainless steels, by the addition of bismuth ; and, in Monel Metal, by the addition of sulphur.

Free-Cutting (Free-Machining or Easy-Cutting) Steels. Steels which, by virtue of their composition and structure, are more readily machinable than ordinary s. Carbon s. may contain : (a) a high phosphorus content, giving rise to a general and frequently an exaggerated local brittleness ; (b) high contents of sulphur and manganese, giving rise to a large number of inclusions or local discontinuities in the tougher metal ; (c) a proportion of lead. All of these constituents promote machinability, and classes (b) and (c) are still excellent mechanically. In stainless s., additions of 0.1-0.5 per cent. of bismuth markedly increase machinability without prejudice to corrosion resistance ; while sulphur and selenium are also used.

Freezing (or Solidifying) Point. The temperature at which the regular rate of cooling of a metal or alloy is temporarily arrested, by reason of the evolution of heat (the latent heat of solidification) on changing from the liquid to the solid state at the same temperature. Pure metals, eutectic alloys and pure intermetallic compounds show a definite f.p., at a constant temperature. Alloys on cooling often solidify over a range of temperature, during which the mass is

partly solid and partly liquid, the proportion of the latter gradually diminishing.

Freezing Point Curve. *See Liquidus.*

Freezing Range. For a cooling alloy, the range of temperature between the first appearance of a solid phase and complete solidification. In a constitutional or equilibrium diagram, it is given by the distance between the liquidus and solidus curves for the alloy in question.

Fretting (Fretting or Chafing) Corrosion. A mutual c. at the contact faces of closely-fitting machine parts when subjected to vibration. Among such parts are ball-race housings, spline fits, shafts and hubs of keyed gears, engine bearings, collets, etc. The effect is shown as pitting and c. in irregular patches, with the production, usually, of a dark brown powder. The affected areas on the two surfaces are generally almost identical with each other, showing that there has been no sensible movement between them during the process. The effect in question differs from that caused by ordinary wear, as in sliding friction, in that it is found on such contact surfaces as forced and shrink fits, where the parts are supposed to be fixed in relation to each other. Again, although the presence of oxidation products shows that c. enters into the process, vibration appears to be also an essential factor, there being no such surface deterioration if the machine remains at rest. It would appear that vibration or alternating stress beyond certain limits may give rise to relative movement between the two surfaces, to cause surface slip, alternating in direction, leading to attrition on a molecular scale, rather than a merely mechanical grinding or abrasion. Thus, in spite of the accompanying c., the process of fretting c. can be regarded as primarily of a mechanical rather than a chemical nature. The rapidity of the c., and the amount of oxide produced, are proportional to the relative movement, but are independent both of speed and load. C. is at a maximum with stainless and hard steels; while soft steels (and soft materials generally) tend more to seize and less to produce c. débris than hard steels. C. is at a minimum between pairs of metals having the greatest difference in hardness. The effect of f.c. is to reduce the fatigue strength greatly.

Fringe Crystals. *See Columnar C.*

Full Annealing. Heating iron-base alloys above the critical temperature range, holding above that range for a proper period of time, followed by slow cooling through the range. The a. temperature is generally about 100° F. above the upper limit of the critical

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temperature range, and the time of holding is usually not less than 1 hour for each inch of section of the heaviest objects being treated. The objects being treated are ordinarily allowed to cool slowly in the furnace. They may, however, be removed from the furnace, and cooled in some medium which will prolong the time of cooling as compared to unrestricted cooling in the air. (Joint Cttee. of A.S.T.M., S.A.E. and A.S.M.)

G

Galling (or Seizing). In Powder Metallurgy, the impairment of the surface of a compact, and/or of the die parts, due to friction (A.S.M. Defn.).

Gallium. Ga. El. A.W. 69.72; At. No. 31; S.G. 5.90; M. Pt. 30° C. Soft greyish white metal with brilliant lustre, tarnishing quickly; not very malleable. Occurs in minute quantities in a great variety of minerals, but obtained only as a by-product from copper manufacture at Leopoldshall in Germany. Extracted by a complex process. Used chiefly as a backing for special optical mirrors and as an alloy for dental fillings. The boiling point is 1700° C., giving a long thermal range of stability for the liquid phase. G. has therefore been used for filling quartz thermometers for registering temperatures above 500° C.

Galvanizing (Hot-Dip Process). A rust-proofing process for steel, by coating with zinc, resistance varying with thickness of coat. As applied to sheets, these are close-annealed to render them soft, pickled, washed and passed into a bath of molten zinc at a temperature of 450° C., the surface carrying a flux layer of zinc chloride and ammonium chloride. A composite coat results, with an exterior layer of almost pure zinc and an inner layer of zinc-iron alloy, constituting the bond. Excess zinc is removed by passing through rolls immediately after immersion; after which the plates are cooled and straightened in a flattening machine, and may then be formed into corrugated sheet. The crystallized zinc has a spangled appearance, the crystal size being regarded as an indication of quality. The advantage of g. is that, if any part of the steel becomes exposed, it is cathodic to zinc, and is still in some measure protected from attack. *See also Electro-Galvanizing.*

Gamma Iron. I. existing at temperatures between A_4 ($\delta \rightarrow \gamma$ transformation point on cooling; or *vice versa* on heating) and A_3 ($\gamma \rightarrow \alpha$ transformation point on cooling). It readily dissolves carbon, is non-magnetic, and has a crystal structure of face-centred cubic type. The position of the A_4 point varies with composition and is discussed under *Delta Iron* (q.v.). The position of the A_3 point also varies with composition, between about 900° and 700° C. In hypoeutectoid steels in this range there is a gradual conversion of γ - into α -iron (or *vice versa*), the residue of γ being finally transformed at the lower temperature, with evolution of heat, into the eutectoid

Gam

of α -iron and cementite, known as *pearlite* (q.v.). The solid solution of carbon in γ -iron is known as *austenite* (q.v.).

Gamma Loop. In a binary constitutional diagram covering alloys of iron and an element which acts as a stabilizer of ferrite, a restricted area in the shape of a closed loop, delimiting the compositions and temperatures at which the γ -phase occurs. The progressive addition to iron of a ferrite stabilizer (as chromium, tungsten, molybdenum, silicon, aluminium or titanium) gradually depresses the A_4 point (the $\gamma \rightarrow \delta$ transformation, which occurs in pure iron at 1404°C .) and raises the A_3 point, until the two are one, the g.l. thus terminating, so that only α -iron occurs at all temperatures up to the melting point. Outside the area of this loop, no critical points occur, and the alloys (as those containing 11.6 per cent., or more, of chromium, or 5.5 per cent., or more, of tungsten) are not susceptible to the usual heat treatment. The effect of a ferrite stabilizer can of course be corrected by the addition of an austenite stabilizer (as manganese or nickel) in suitable proportion, the steel being then once more amenable to the usual heat treatment. Where a ferrite stabilizer is present in amount insufficient to merge A_4 and A_3 , the resultant raising of A_3 will require that normalizing for grain refinement, or other heat treatment, shall be carried out at a higher temperature.

Gamma Rays. X-rays, *i.e.*, electromagnetic waves of very short wave-length (about 10^{-9} cm.), separated by a long interval from the short ultra-violet rays, but, like them, producing conductivity in a gas. Their penetrative power is much higher than that of β -rays. Quanta of γ -radiation are always emitted by nuclei, sometimes spontaneously, very shortly after the ejection of either an α - or β -particle. γ -rays are spontaneously emitted from Thorium C' with an energy of 2.65×10^6 electron volts; a more penetrating beam being produced by the action of a beam of α -rays upon beryllium, the energy being 5×10^6 electron volts. G.r. are used in radiography (q.v.).

Gas Carburizing. C. (q.v.) direct by means of gases, usually a mixture of gaseous hydrocarbons from natural oil wells, suitably admixed with air, such as is readily obtainable in many parts of the U.S.A. Results from the use of gas from raw coal, or town's gas, are inconsistent, explaining the lack of development of the process in this country.

Gassing of Copper. A defect to which tough-pitch copper is liable when heated in reducing atmospheres (as in annealing, or when welding with a reducing flame), in which the particles of

cuprous oxide (Cu_2O) contained in it are reduced by the action of such gases as hydrogen and carbon monoxide, which can diffuse into the metal, more readily along the crystal boundaries. The resultant water vapour or carbon dioxide is much less readily diffusible and the pressure thus generated gives rise to enlarged cavities tending to destroy intercrystalline cohesion, and also to set up cracks. Gassed copper is brittle and of poor mechanical quality.

Gate. (1) *See Runner.* (2) The opening in a pair of rolls.

Gel. *See Colloid.*

Gerber's Law relates the safe range of stress to the corresponding mean stress, and to the ultimate stress of the material, by the following approximately parabolic relation :

$$f_{\max.} = \frac{f_{\max.} - f_{\min.}}{2} + \sqrt{f^2 - nf(f_{\max.} - f_{\min.})}$$

where $f_{\max.}$ and $f_{\min.}$ are the limiting stresses for the safe range, f is the ultimate stress and n a constant for the material. This l., as with various others that have been put forward, is not of universal application.

Germanium. Ge. El. A.W. 72.60 ; At. No. 32 ; S.G. 5.47 ; M. Pt. 900° C. Greyish white very rare metal, very resistant to corrosion. Occurs as *argyrodite* ($3\text{Ag}_2\text{S} \cdot \text{GeS}_2$) and very widely distributed in minute quantity in various minerals, coals, etc. Extracted from zinc-plant residues at the Anaconda plant at Great Falls, Mont. A possible industrial application is in plating ; it is deposited electrolytically from strong aqueous solutions of the dioxide in potassium hydroxide. As an addition to tin, 0.35 per cent. of g. increases the Brinell hardness by 100 per cent., with some decrease in strength and ductility.

Ghost (G. Line or Structure, or Ferrite G.). A band or streak, which may be of considerable breadth, sometimes shown on machined surfaces of steel, as of a somewhat lighter colour and often just visible only when viewed at a particular angle, whence the term. A g. is a segregated region arising originally during solidification and then elongated in working, containing higher proportions of phosphorus (in solution), an excess of sulphide inclusions, and composed substantially of ferrite only, instead of ferrite and pearlite. Being harder than the remainder of the metal, a g. tends to stand in slight relief on machining. The material composing it is of much inferior quality, particularly in shock resistance, and the defect cannot be corrected by heat treatment.

Glo

Globular Cementite. See Spheroidal C.

"Globular Pearlite". See "Divorced Pearlite".

Gold. Au. El. A.W. 197.20; At. No. 79; S.G. 19.32; M. Pt. 1063° C. Bright yellow metal, rather soft, very malleable and ductile; very resistant to corrosion. Occurs usually native in quartz veins as *reef gold*, and in alluvial gravels as *alluvial gold*; in a few rare minerals, and widely distributed in small quantities in many minerals, sea water, etc. Usually contains silver and copper as impurities. Extracted from ore and sand by the cyanide, chlorination or amalgamation processes. G., suitably hardened by the addition of copper or silver, is used in coinage, jewellery and dentistry. G. is also used as an electro-deposited coating. An important use is in the decoration of pottery, where it is applied either as "liquid gold", a suspension of finely divided g. in certain essential oils; or as "potter's gold", a fine amorphous powder, containing g., mercury and various fluxes. There are various minor applications.

Goldschmidt Process. See Thermit P.

Graduated Hardening. A process depending upon the fact that the austenite → martensite transformation in tool steels does not occur instantaneously, but during the cooling range of about 300°–180° C., according to the composition. The tool must thus be cooled at a rate greater than the critical cooling rate (q.v.), and then more slowly, the tool then having sufficient time to undergo, without fracture, the change in dimensions during this transformation.

Grain (or Crystalline Grain). The individual allotriomorphic crystal present in a metal or a one-component alloy. A twinned crystal, including the twinned layers, is only one g. In alloys with two components (as steels or Muntz Metal), the original g. giving rise to the aggregate is the unit g., if its limits are still discernible; otherwise, the individual components are regarded as g. When g. sizes are specified, the term must always be defined.

Grain Boundary. The surface separating adjacent g.—usually of differing orientation—in a polycrystalline aggregate. At the g.b., the regular pattern, or lattice, on which the atoms of the individual g. are located, becomes distorted, for the atoms in this transitional region are influenced by forces arising from the lattices of each of the g. The change in orientation at the g.b. is akin to a break-of-joint in brickwork; slip occurs less readily, and the material at the g.b. of worked alloys is therefore usually stronger than that in the

g. itself. In general, fine-grained are stronger than coarse-grained structures. In cast metals, however, impurities may segregate to, or minute shrinkage cavities occur at, the g.b. In annealed alloys, other phases may be precipitated selectively at g.b. Corrosion or cracking may thus occur preferentially at g.b., as in the case of caustic embrittlement, season cracking and weld decay (q.v.). Creep (q.v.) is due partly to g. slip, and partly to movement at the g.b., the relative reduction in creep resistance, with temperature, at each of these positions being uncertain.

Grain Count. See Grain Size.

Grain Growth. An increase in the average g. size of a metal or alloy, some g. growing larger, by boundary migration, at the expense of others, with resultant increase in size and reduction in number of the g. composing the mass. G.g. is promoted by slow cooling during solidification; and also by annealing, becoming greater with temperature and period. The annealing of cold-worked metal may lead to abnormal g.g. with certain critical conditions of strain and annealing temperature. By special deoxidation, as with aluminium, steels can be obtained in which g.g. proceeds more slowly, the production of a definite austenite g. size thus requiring a higher annealing temperature.

Grain Refinement. The process of refining a coarse-grained structure, which can be effected as follows: (1) By hot working (q.v.). (2) If the metal or alloy in the solid state exhibits either an allotropic change, or a phase change of eutectoid type, recrystallization will occur on transformation, a fine-grained structure usually resulting. The transformation temperature must only just be exceeded, and the material must not be kept too long at the temperature, or g. growth will once more occur. The normalizing of steel is such a process; aluminium bronze being also amenable to this type of g.r. (3) A universal type of g.r. is obtained by the annealing of cold-worked metal, *e.g.*, brass, at a suitable temperature, when recrystallization occurs, and a fine-grained structure can be produced. The appropriate annealing temperature depends on the material, and the extent of the previous cold work. The greater the latter, the lower the temperature of recrystallization, and the finer the g. size.

Grain Size is variously expressed as the average diameter, dimensions, or number of g. per unit cross-sectional area. For strained material, it may be returned as the average number per linear unit in two directions, or per unit cross-sectional area, together with the ratio of length to breadth. The intercept method of g. count determines the number of g. and fractions of g. along a line of

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given length on two axes at right angles to each other ; and the planimetric, the number of g. and fractions of g. within a given area. G.s. in steel refers primarily to austenite g.s., which exists only when the solid steel is above A_{c_1} . With a smooth surface and non-oxidizing atmosphere, austenite g. can actually be seen in the furnace. In steels slowly cooled, the original austenite g.s. can be determined in the cold by the ferrite network in hypo-eutectoid and the cementite network in hyper-eutectoid steels ; as well as in other ways. Austenite g.s. are classified by the A.S.T.M. (E19—39T) in eight sizes, Nos. 1-8, numbers which relate to the mean g.-section s., as viewed on the metallographic specimen at a magnification of 100 diameters. Coarse-grained metals and alloys are generally, but not always, mechanically inferior to fine-grained ones. Coarse-grained steels have, however, greater hardenability.

Gram-Ion. The total of the atomic weights of the atoms in an i., expressed in g. Thus, the electrolytic dissociation of ammonium chloride gives rise to the i., NH_4 and Cl , with g.-i. of $14.008 + (4 \times 1.008)$, or 18.04 ; and 35.457, respectively.

Granular. In Powder Metallurgy, a formation of metal powder particles in approximately equi-dimensional non-spherical shapes (A.S.M. Defn.).

“ Granular Pearlite ”. See “ Divorced Pearlite ”.

Granulation. (1) A method of increasing the ratio of surface area to volume of a metal. In the g. of zinc, the molten metal is usually poured from a ladle into a pailful of water placed some 3 to 4 ft. below it. (2) In Powder Metallurgy, the production of coarse metal particles by pouring the molten metal through a screen into water, or by violent agitation of the molten metal while solidifying (A.S.M. Defn.).

Graphite. (1) A naturally occurring allotropic form of carbon, also known as *plumbago* and *blacklead*, used as a refractory. (2) The state in which much of the carbon in pig and cast iron exists. Iron-g. is a stable and iron-iron carbide a metastable system, and g. thus results from the decomposition of some of the iron carbide during cooling in the solid state, its production being promoted by slow cooling, a high content of silicon and a low content of sulphur. G. may also be liberated on subsequent annealing, as in the manufacture of malleable cast iron (q.v.). In grey cast iron (q.v.), g. is the determining factor, the variation in quantity and type deciding the mechanical quality. A classification of g. types is given in

A.S.T.M. Stds. A247—41T, on "Evaluating the Microstructure of Graphite in Gray Iron".

Graphitizing. (1) An annealing process applied to mottled or white cast iron, by which the combined carbon is wholly or in part converted to graphitic or free carbon (*see Malleable Cast Iron*). (2) The addition, to molten cast iron in a ladle, of a reagent with a g. effect (*see Inoculated Cast Iron*).

Grey Iron. *See Cast Iron.*

Grinding. (1) A workshop operation involving the removal of surface metal, and the production of a smooth and polished surface, by contact with a revolving disc composed of, or covered with, a suitable abrasive. (2) A similar but much more delicate operation used in the preparation of samples for metallographic examination. Here the abrasive grains are very much finer, much less metal is removed, and the object is to remove surface metal without disturbing the underlying metal.

Groundmass. *See Matrix.*

Growth. In Powder Metallurgy, the increase in dimensions of a compact which occurs during the sintering (A.S.M. Defn.). *See also Grain G.*

Guillet's Equivalent. The zinc-replacement capacity of an additional metal added to brass (q.v.) to increase strength, corrosion resistance, etc. The metals commonly added, together with their "zinc equivalence" according to G., are as follows: aluminium, 6; tin, 2; lead, 1; iron, 0.9; manganese, 0.5; and nickel, — 1.3. Thus 1 per cent. of tin has the same effect upon the microstructure of the alloy as 2 per cent. of zinc; while 1 per cent. of nickel is equivalent to a reduction of 1.3 per cent. of zinc. These factors are reasonably accurate so long as the amount of the particular element added does not exceed 2 per cent.

Gunmetal. *See Bronze.*

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Hair-Line Cracks (or **Hair C.**). (1) Fine c. produced in steel which has been cooled rapidly through the A_{r1} point. These are not merely stress c., because they are not produced immediately on quenching, but only after a period of ageing. Further, they result only when hydrogen has been dissolved by the steel during the earlier melting and refining processes, or even during heat treatment. Heat treatment *in vacuo*, or nitrogen, does not give rise to h.-l. c. Although hydrogen is thus a major factor in their production, the exact mechanism of the process is still uncertain. It is believed that h.-l. c. can be corrected by re-forging, if sufficient work is done. (2) The term is also applied to *any* fine crack which may occur in metals and alloys.

Hair Seam. *See* Seam.

Half-Hard. *See* Quarter-Hard.

Half-Life (or **Half-Value**) **Period.** The time required before a given number of atoms of a radioactive element have been reduced to half by disintegration.

Hammer Refining. *See* Mechanical R.

Hammer Scale. The s. (q.v.) produced on heating steel, and cracked and broken away by working under the hammer.

Hard. *See* Quarter-Hard.

Hard Centre. An effect resulting from insufficient soaking on heating, so that the interior metal is not brought to the temperature required, and is consequently worked at too low a temperature.

Hard Chromium Plating. *See* Chromium-Deposition.

Hard-Facing. *See* Hard-Surfacing.

Hard Metal Tools. *See* Sintered Carbide Tools.

Hard Soldering. *See* Brazing.

Hard-Surfacing. Any process in which one applies to a metallic surface a treatment or coating making the surface very hard and

wear-resistant, or suitable for use as a cutting tool. Among such processes are carburizing or case-hardening, nitriding, chapmanizing and cyaniding, in which the surface layer is impregnated with carbon or nitrogen, or both, by heating in contact with suitable reagents, followed (if necessary) by quenching ; flame or induction hardening, in which the normal surface layer is locally hardened by heat treatment ; the spraying of hard materials, as of high-carbon steel on to low-carbon steel ; the electro-deposition of hard metals (as of chromium on steel) ; the application of hard surface coatings by fusion-welding processes (as the Stellite and Toolweld processes for the production of wear-resistant parts and of tools).

Hardenability. That characteristic of a steel rendered austenitic by heating which determines its capability to harden throughout (*i.e.*, to develop its maximum martensitic hardness) when quenched, being thus a direct function of the critical cooling rate ; and, as such, independent of external quenching conditions. The intensity of maximum hardening, which depends chiefly upon the carbon content of the steel, is not involved. Owing to the varying rate of cooling in a quenched round bar, greater towards the surface and lowest at the centre, the critical cooling rate in larger bars is reached at a certain depth, representing the depth of hardening ; which, for given quenching conditions, is greater, the greater the *h*. A steel of greater *h*. can be hardened by using slower rates of cooling. Carbon steels, which require quenching in water for adequate hardening, have therefore lower *h*. than many alloy steels, which can be suitably hardened by the milder process of oil-hardening. Thus the capability of a steel to surface-harden is determined largely by its carbon content ; its capability to depth-harden by the addition of alloying elements, such as chromium and manganese. With parts of larger section, the use of alloy steels is essential if adequate depth-hardening is to be ensured. *H*. varies directly with the austenite grain size existing in the steel at the moment of quenching, fine-grained steels thus having lower *h*. See also **Jominy End-Quench Test**.

Hardenability Line. When plotting, for bars of various diameters, the fractional depth of hardening against the inverse square of the diameter (method of Queneau and Mayo), a straight line through the points is termed the *h.l.*

Hardeners. Alloys prepared for the purpose of adding small quantities of additional elements to molten metals. To avoid too great an addition to the melt, entailing undue reduction in temperature, *h*. are usually rich in the required element, which often exists

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as an intermetallic compound. H. are therefore frequently brittle, facilitating ready preparation of the quantity required.

Hardening. The heating of steel to a temperature above its critical temperature range, *i.e.*, above its A_{c_1} point, followed by cooling through that range at a rate which is sufficiently rapid to prevent or retard the austenite \rightarrow pearlite transformation, such rapidity of cooling usually requiring, with carbon steels, quenching in oil or water. If this critical cooling rate (q.v.) is not exceeded, the transformation is depressed to a temperature such that martensite is produced, and the steel is hard. Analogous changes occur in other alloys, as aluminium bronze.

Hardenite. A term, now obsolete, applied to martensite of exactly eutectoid composition. This has often a fine and apparently rather indeterminate structure, the usual acicular constituent being not readily observable by the earlier methods of etching and examination. The improvement in technique has now invalidated the distinction.

Hardness. That quality of a material by virtue of which it resists the local displacement or removal of portions of its substance. From this definition, h. might at first be regarded as synonymous with rigidity. This, however, is not so. The stress applied in any h. test is a very complex one, which has deformed and possibly partly disintegrated the material, and can thus constitute no measure of its rigidity, as shown, for example, by the fact that cast iron is decidedly harder than mild steel, which is more than twice as rigid. H. tests should thus determine the ability of a material to support severe loads, to resist wear, and so forth. See **Brinell H. Test**, **Diamond Pyramid H. Test**, **Herbert Pendulum H. Test**, **Monotron H. Test**, **Rockwell H. Test**, **Scleroscope Test**, **Scratch H. Test**, etc.

Hardness, Potential Maximum. Of steel, the maximum h. of the martensite produced on quenching; this, in the plain carbon and the common alloy steels, being very largely a function of the carbon content of the steel. P.m.h. differs from hardenability (q.v.).

Hardometer. See **Diamond Pyramid Hardness Test**.

Hartmann Lines. See **Stretcher Strains**.

Healing. The welding up of cracks in an ingot, such as may be caused in the first few rolling passes, during subsequent rolling. H. will occur only if the carbon content of the steel is not too great and the metal is sufficiently hot.

Heat, Latent. See Latent Heat of Fusion and of Vaporization.

Heat Refining. Reheating steel to just above its critical range, *i.e.*, above A_{c_3} —a margin of 50°C. , or so, above this temperature being usually allowed—followed by fairly rapid cooling through the critical range. The object is to produce a structure of fine-grained austenite, which transforms later into one composed of fine-grained ferrite and pearlite.

Heat-Resisting Cast Irons. The causes of failure of c.i. at elevated temperatures are: (1) Breakdown of the carbides, particularly iron carbide, with resulting graphitization, consequent local increase in volume and the development of stress. (2) Cracking due to unequal expansion of the graphite and the matrix. (3) Surface and internal corrosion and oxidation by gases, which penetrate along cracks and between constituents. These effects can be resisted: (a) by the addition of a carbide stabilizer (chromium, manganese, tungsten, molybdenum or vanadium) in sufficient amount; (b) by the addition of such a reagent (silicon, aluminium, titanium or nickel) as to produce a matrix of ferrite, containing fine graphite, with a transformation temperature above that to which the material must be heated. An example is Silal, containing 5-7 per cent. silicon. On heating, there is practically no carbide to decompose, and therefore no change in volume, while the fine graphite reduces gas penetration to a minimum. Such irons are very resistant to heat, but are weak and brittle under thermal stresses; (c) by the production of an austenitic matrix, such as can be obtained by the addition to Silal of 18 per cent. of nickel, when the strength is increased, and is still further enhanced by chromium; while the material (Nicrosilal) has good heat-resisting properties. A typical composition is 18 per cent. nickel; 6 per cent. silicon; 2 per cent. chromium and 1.8 per cent. carbon; with a tensile strength of 16 tons per sq. in. and 3 per cent. elongation.

Heat-Resisting Steels. These s. fall into two classes: (1) Those required to work at the moderate temperatures used in steam plant, generally not exceeding about 750°F. , with 850°F. as a reasonable maximum, temperatures at which only the effects of "creep" (q.v.) have to be considered. The temperature at which carbon steels become inadequate, by reason of creep, is about 800°F. or 425°C. , the limiting temperature varying somewhat with the operating stress. For the higher steam temperatures, creep-resisting s., as carbon-molybdenum, chrome-molybdenum and nickel-chrome-molybdenum s., must be employed. (2) Those required to work at the very much higher temperatures used in furnaces and similar high-temperature plant, *e.g.*, at 1100° or even exceptionally at

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1200° C. Such s. must adequately maintain their dimensions; show sufficient resistance to scaling or corrosion, as by sulphurous atmospheres; and maintain sufficient strength at the operating temperature. Scaling is resisted by the formation of an adherent non-porous oxide film, as can be obtained by the addition of silicon and chromium—usual constituents of valve s.—while the maintenance of mechanical quality at high temperatures is promoted by the addition of tungsten and molybdenum.

Heat, Specific. *See* **Specific Heat.**

Heat-Tinting. A method of developing the microstructure of a metal or alloy by heating a polished metallographic specimen in air, to produce selective oxidation of particular constituents. The process is preferably carried out after a light etch, to remove the altered surface film produced in polishing. It has been found very useful for the determination of varying phosphorus segregation in steels, and the intensification of the copper phosphide constituent in cast phosphor bronzes; but it has in general only a restricted application.

Heat Treatment. A combination of heating and cooling operations applied to a metal or alloy in the solid state to obtain desired conditions or properties. Heating for the sole purpose of hot working is excluded from the meaning of this definition. (Prop. Std. Defn., A.S.T.M., 1942.)

Heating Curve. *See* **Cooling Curve.**

Hemihedrism. An effect occurring particularly in the hexagonal system (q.v.), in which only alternate planes of the fundamental crystal form are found. The development only of alternate planes of the hexagonal pyramid produces a rhombohedron, with six similar rhombic faces. H. is shown by antimony, arsenic and bismuth.

Herbert Pendulum Hardness Test utilizes the alteration in the time of swing of a pendulum caused by change of the centre of oscillation when a spherically-shaped diamond indenter—on which the pendulum is supported—moves in the groove made by itself. The “time test result” is defined as the time of 10 single swings of the pendulum, this being a measure of the size of the indentation produced in the material being tested, the results being thus related to Brinell hardness numbers. Typical values are 70 seconds for hardened tool-steel and 20 seconds for mild steel.

Heterogeneous. A term describing metals and alloys with structures composed of more than one constituent.

Hexagonal System. A s. of crystallization in which there are three equal lateral axes, all lying on one plane and each intersecting its neighbour at an angle of 60° ; while the principal axis is at right angles to this plane and is of different length from the lateral axes. The fundamental form is the double h. pyramid. H. crystallization is shown by magnesium, zinc and cadmium.

High-Carbon Steel. S. containing c. in excess of about 0.6 per cent. No sharp line of demarcation between h.-c.s. and medium c.s. (q.v.) is universally recognized.

High-Duty Cast Irons. A term used to denote two distinct classes: (1) Those of high strength (high-test c.i., q.v.), such as are obtained by improving the properties of the matrix, and controlling the graphite quantity, distribution, flake size and shape. (2) Those with some special characteristic, such as high resistance to corrosion or high temperature (austenitic and heat-resisting c.i., q.v.), where the enhanced properties are often due to the development of special structural constituents by means of additional alloys. Class 1 is covered by B.S. Spec. No. 786: 1938, for High-Duty Iron Castings, compiled "in view of the demand for improved grades of cast iron having a tensile breaking strength greater than 12 tons per sq. in.", and specifying three grades which are to show minima of 15, 18 and 22 tons per sq. in., respectively, when cast as test bars $\frac{7}{8}$ in. in diameter. C.i. of high strength are obtained: (a) by reducing the total carbon content by using in the charge sufficient low-carbon pig iron and steel scrap; (b) by adjustment of the carbon/silicon ratio to obtain minimum graphite, without producing either free ferrite or free carbide; (c) by treatment of the molten iron with soda ash, to act as a scavenger, and (d) by graphitizing with a suitable ladle addition (*see Inoculated C.I.*). Superheating (q.v.) may be employed. Special alloys, to balance the composition and improve the matrix, may also be added.

High-Speed Steels. Tool s. containing such proportions of alloy constituents—tungsten, molybdenum, vanadium, chromium, cobalt, etc.—as will enable the tool, when hardened, to cut without breaking down at a very much higher speed than with an ordinary carbon s. tool. The hardening process consists in rapid cooling from above the A_c point; when, in the presence of the alloying elements in proportion suitable to the method employed, the cooling change point (A_{r1}) is greatly depressed, and the s. will readily air-harden, while the resulting martensite requires, for its destruction, a tempera-

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ture very much higher than with the martensite of carbon tool s. Maximum hardness is obtained by a maximum solution of the alloy carbides, which are much more insoluble than ordinary cementite, and a high hardening temperature is therefore required. Some residual carbides, however, are always present after hardening. A well-known h.-s. s., 18: 4: 1, contains these proportions of tungsten, chromium and vanadium, respectively; with some 0.6–0.7 per cent. of carbon. Scarcity of tungsten has led to a reduction in the proportion of this constituent in h.-s.s., and its partial replacement by molybdenum.

High-Tensile Brasses. A range of casting and forging alloys, comprising $\alpha + \beta$ and full β b., possessing high strength, good ductility and showing excellent resistance to corrosion. They are obtained by the addition, to ordinary b. (q.v.), of various other metals, as Al (0–5), Fe (0–2), Mn (0–3.5), Ni (0–10) and Sn (0–1.5), the range used being indicated by the percentage in brackets. Each has its own particular effect on the alloy. Several may be used together, when a suitable “balance” between them must be obtained. As with zinc, the added metal often influences the structural make-up of the alloy (*see Guillet's Equivalent*). By suitable variation of composition, casting alloys varying in strength from 28 to 45 tons per sq. in., with elongations varying from 25 to 12 per cent., may be obtained. Manganese bronze (q.v.) is the best-known h.-t. b.

High-Test Cast Iron. C.i. showing a tensile strength not below a certain arbitrary value, varying with different authorities. Thus minimum figures of 40,000 lb. (17.85 tons) or 22 tons per sq. in. have been suggested. *See High-Duty C.I.*

Hollow-Drawing (or Over-Drawing). An effect in which too severe a degree of cold working—as may be due to insufficient intermediate annealing—so reduces the ductility of the material as to cause local failure, shown by the development of transverse internal fissures. There is often no external evidence of h.-d.

Homogeneous. (1) Metals and alloys having structures composed only of one constituent are said to be h. (2) Those showing no blowholes or porosity, and thus completely solid, are sometimes so described.

Homogenizing. A high-temperature heat treatment for the purpose of removing or diminishing segregation, by diffusion. With magnesium alloys, h. is simply a solution treatment (q.v.),

which may or may not be followed by an ageing treatment before the part is put into service.

Homopolar Linkage. See **Electronic Theory of Valency.**

Hooke's Law. A l. deduced by Thomas H. in 1676, embodying "the true theory of elasticity", and laying down that, "as the stretching is, so is the strength"; or, as it may now be expressed, within the elastic limit, strain is directly proportional to stress.

Hot Pressing. (1) See **Pressing.** (2) In Powder Metallurgy, the simultaneous forming and heating of a compact (A.S.M. Defn.).

Hot Quenching. A process of quenching iron-base alloys in a medium, the temperature of which is substantially higher than atmospheric. (Prop. Std. Defn., A.S.T.M., 1942.)

Hot Shortness. Brittleness in metal when hot, shown: (a) in wrought alloys, by a lack of ductility and a liability to crack when hot-worked, as with duralumin above 470° C.; (b) in cast alloys, by a liability to tear or crack under the stresses which may be set up during cooling in the mould, *e.g.*, by core irons too tight, or cores too hard, or by the prevention of normal contraction by projecting fins or flash, as shown by many aluminium alloys. H.s. is also shown by alloys containing a eutectic when deformed at temperatures higher than the melting point of the eutectic.

Hot Top. See **Sinkhead.**

Hot Working. The mechanical working of metal above the recrystallization temperature; for steel, above the A_c_3 point; and usually, to ensure sufficient plasticity for satisfactory working, at 1200° C. or higher. At such temperatures, there would be a rapid coarsening of the austenite grain size, if it were not for the mechanical work, which continuously breaks down the coarse crystals, while the temperature causes a continuous re-annealing, the grain size remaining small. This temperature-work balance can be obtained more readily in rolling than in forging.

Hydrogen Embrittlement. See **Pickling.**

Hydrogen-Swell. The swelling, in storage, of a "tin-can" containing fruit, by reason of the evolution, within the can, of hydrogen, formed by the corrosion of the tin plate by the fruit acids, resulting in a "blown" or "domed" can, which may later become actually perforated, and is in any case unmarketable. The effect

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may be minimized by using tin plate with a copper content of about 0.20 per cent. and a phosphorus content as low as pack-rolling considerations will allow.

Hyper-Eutectic and Hypo-Eutectic. Hyper-e. alloys contain an excess of one constituent of a binary system over that shown by the e. alloy. Hypo-e. alloys show a deficiency of the same constituent as compared with that shown by the e. alloy. The same prefixes are similarly employed for alloys containing a eutectoid.

Hyper-Eutectoid Steel. S. containing carbon in excess of the e. proportion of about 0.85 per cent., and therefore consisting, under conditions of slow cooling, of a mixture of pearlite and cementite.

Hypercarb Process of Gas Carburizing. A p. of applying a controlled high-carbon case to steel parts by heating at a regulated temperature for a controlled time in an atmosphere containing hydrocarbons and carbon monoxide in suitable proportions. Before allowing the gases to come into contact with the steel, they are heated to some 870–925° C., when they become much more reactive, and carburization is proportionately accelerated.

Hypo-Eutectoid Steel. Steel containing carbon in quantity less than the e. proportion of about 0.85 per cent., and therefore consisting, under conditions of slow cooling, of a mixture of ferrite and pearlite.

Hysteresis, Mechanical. *See Mechanical Hysteresis.*

Hysteresis, Thermal. *See T. Lag.*

I

Ideal Radiator. *See Black Body.*

Idiomorphic Crystals. C. of which the external form results from the internal structure ; as with c. growing freely without interference, when they assume their natural geometrical shapes.

Ihrigizing. A process of producing on steel a high-silicon heat- and corrosion-resistant surface layer by heating the parts at a temperature of about 1000°C . in boxes with metallic silicon or other siliceous materials. The case, containing about 14 per cent. of silicon, is said to withstand highly oxidizing atmospheres up to 1000°C ., and to resist boiling in 10 per cent. sulphuric acid for over 100 hours.

Immersion Heating. H. in a liquid medium, as oil, molten lead or a salt bath, to ensure that the part is uniformly heated.

Impact Testing. A toughness test in which, usually, a test bar, supported either as a cantilever or a beam, and arbitrarily notched, is broken by a single blow suddenly applied by means of a calibrated pendulum, the toughness value of the material being expressed in terms of the energy absorbed in fracture. The basis of the test is the assumption that shock resistance depends upon the capacity of the material to reduce the intensity of local stress by plastic flow, and the purpose of the notch is to produce this intense local concentration. Material may thus be described as "notch-tough" or "notch-brittle", depending upon the value obtained. There are two well-known methods of i.t., the Charpy and Izod tests (q.v.). *See also Notch Brittleness and Notch Sensitivity.*

Impregnation. In Powder Metallurgy, the process of filling the pores of a sintered compact, usually with a lubricant (A.S.M. Defn.).

Incandescence. The light given out by a body by virtue of its high temperature. With a black body, the total radiation varies directly with the fourth power of the absolute temperature.

Incipient Shrinkage (or Inter-Dendritic Porosity). A solidification-shrinkage effect found in alloys, *e.g.*, bronze, having an extended solidification range, and particularly in castings of heavier and variable section, which may show the presence of inter-dendritic microscopic cavities, connected to a greater or lesser extent with each

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other, and associated with low strength and ductility ; in extreme cases, even with unsoundness under the water test. These cavities have the same origin, but are much smaller in degree than the usual shrinkage cavities of the foundryman. In addition, they may contain gas rejected to the crystal boundaries during solidification. They occur much more frequently in metal which has been melted in a reducing atmosphere.

Inclusions. Non-metallic phases which are not constituents of the particular alloy system, but are included or entangled in the metal, whether in the solid or liquid state. In the second case, they may partially separate before solidification. I. may originate from the ore in smelting, when they consist of slag or gangue ; from the furnace lining, when they may also be described as "slag" ; from reactions caused by deoxidizing or other additions to the molten metal in processing ; or from reactions occurring during solidification. In sand castings, i. of moulding sand may also be found. Being lighter than the metal, i. tend to concentrate in the upper portions of the ingot in solidification and also to segregate to the crystal boundaries. I. in steels may consist of oxides, sulphides and silicates of iron and manganese, and the oxides of aluminium and titanium in steels treated with these metals ; in bronzes, of oxides of tin or zinc ; and, in aluminium alloys, aluminium bronzes and some manganese bronzes, of alumina. The elongation of plastic i. in the direction of forging or rolling is one cause of "fibre" in wrought steels. I. are usually prejudicial to mechanical quality, in breaking up the homogeneity of the metal and giving rise to stress concentrations at the acute ends of elongated slag threads.

Indium. In. El. A.W. 114.76 ; At. No. 49 ; S.G. 7.13 ; M. Pt. 155° C. Silver-white metal, soft and very ductile. Occurs in small quantities in *zinc blende*, the flue dust from zinc furnaces sometimes containing 0.20 per cent. of i. Its extraction is complex, the metal being finally obtained most suitably by the electrolysis of a solution of the cyanide. Used in the plating of silver to produce an untarnishable alloy ; and also, by plating alternately with gold and i., followed by heating, to obtain a sky-blue finish. I. plated on and diffused into cadmium alloy bearings reduces liability to corrosion without detriment to fatigue resistance or other useful properties. Copper-lead bearings are also impregnated with i. to prevent corrosion by acid oil. Added to the fusible alloy known as Lipowitz' alloy, i. reduces the m. pt. to 46.5° C., when the alloy can be used in surgical work, since the liquid alloy produces no discomfort on the skin.

Inductile. Having no ductility, as with cast iron.

Induction Hardening. A surface-hardening process, applied to medium carbon (0.50–0.55 per cent.) straight or alloy steel, in which only the surface of the part is heated and quenched out, the core remaining unaffected; while distortion is almost negligible. Heating of the steel to above the A_{c_3} point, over the area and to the depth required, is effected by means of eddy currents induced by high-frequency alternating current, usually of 2000 cycles, passed through a copper induction block—acting as the primary coil of a transformer—placed around but not touching the part being treated. After heating for a predetermined time, the high-frequency current is cut off, and the part is automatically spray-quenched by high-pressure water jets delivered on to the heated surface through a large number of perforations in the induction block. Heating is very rapid, the whole operation of heating and quenching a crankpin taking less than 50 seconds. A Shore hardness figure not below 80 can consistently be obtained from the case of a medium-carbon steel obtained in this manner. Since the core of the part remains in its original state, the part must be treated as a whole, to put it into the desired state, before the i.h. process. Cf. **Flame-Hardening**.

Infusible. Having a high m. pt.

Ingot. A special kind of casting for subsequent rolling or forging (A.S.M. Defn.).

Ingot Iron. I. with a very low content of carbon, manganese and impurities, produced in the molten state, and therefore differing from wrought i., which is produced in a pasty condition and always contains some proportion of slag, but may otherwise have much the same composition as i.i. A well-known variety of i.i., known as Armco i., is made in the basic open-hearth furnace, when the excessive oxidation necessary for the almost complete removal of all impurities leads to the presence of ferrous oxide in the metal. I.i. of great purity is also produced by refining in electric furnaces.

Ingotism. A term suggested by Howe to describe the coarsely dendritic structure of cast steels, particularly in the larger sizes of ingot. It is characterized by columnar and equiaxed dendrites, and a general coarseness of the pearlite grains and the membranes of ferrite or cementite, which in part surround them, and are in part located on some of the cleavage planes of the original austenite. Segregation effects are also included in the term, which is sometimes used with alloys other than steel.

Inhibitor (or Restrainer). In general, a negative catalyst (q.v.), tending by its presence to decrease the speed of a particular reaction.

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The term is used in a special sense, however, in pickling (q.v.), a process in which the scale is rarely removed evenly; so that organic reagents (glue, starch, sugar, etc.) are added to the bath, to reduce acid attack and consequent wastage of metal from the exposed clean surfaces during the period in which the remaining scale is being removed. A corresponding wastage of acid is also avoided. When a pickling solution is properly inhibited, the i. reacts with the hydrogen that would otherwise be liberated, so that water only is formed.

Inoculated Cast Irons. C.i. obtained by the addition, to the molten i. in the ladle, of a suitable proportion of graphitizer or inoculant, just prior to casting. The basis i. to which the addition is made has low contents of carbon and silicon, such as would normally give rise to mottled or white castings. This is corrected by the addition of a controlled amount of silicon, or other graphitizer, to "balance" the carbon content; and graphitization is thus delayed until the last moment, the resulting i. showing finely dispersed graphite set in a pearlite matrix. Such i., while grey and machinable, is considerably stronger than ordinary c.i., and can be made of tensile strength from 20 tons per sq. in. upwards, while the strength can be still further enhanced by the use of additional alloying elements, as copper, molybdenum, nickel, etc. Among inoculants are calcium silicide (Meehanite process) and nickel shot and ferro-silicon (Ni-Tensyl process).

Inoculation. (1) A term sometimes applied to the addition, to a super-cooled liquid, of a small crystal of the more stable solid phase which is about to solidify, when the metastable phase is at once transformed entirely into the other. (2) More generally, the term denotes the process of treating molten cast iron in the ladle with an element or alloy which promotes graphitization, such inoculated cast irons (q.v.) being of superior quality.

Inter-Dendritic Porosity. *See Incipient Shrinkage and Porosity.*

Intercept Method for Grain Count. *See Grain Size.*

Intercrystalline Cracking. In a polycrystalline aggregate, c. along the grain boundaries, shown: (a) by metals and alloys when stressed and subjected to corrosion attack. Caustic embrittlement and season c. are particular cases. I.c. is also shown by nickel-copper alloys when exposed to oxidizing and sulphurous gases at the rolling temperature; (b) by metals and alloys in which there is i. weakness due to the presence of some other constituent at the grain boundaries, as by the precipitation of a particular phase during slow

cooling. Thus, duralumin when slowly cooled shows the deposition of CuAl_2 and Mg_2Si at the grain boundaries, leading to i.c. on exposure to sea water. I.c. is also shown by temper-brittle nickel-chromium steels (as may be due to carbide precipitation at the grain boundaries), by "burnt" steel, and by alloys containing a eutectic, when deformed at a temperature higher than the melting point of the eutectic.

Interface. The face common to two adjacent crystals.

Intermetallic Compound. (1) A phase of unvarying composition, in which the component metals occur in fairly simple atomic ratios. (2) A so-called "electron compound" (q.v.).

Internal Friction. *See Damping Capacity.*

Internal Stresses (Residual or Locked-up S.). S. set up and remaining in a metal or alloy, as a result of manufacture or working; as distinct from s. set up by the application of an external force. The i.s. at any point is that proportion of the total s. at the same point which does not vary with the load. I.s., which vary in intensity from one part of a body to another, may be caused by the unequal cooling of castings of irregular section, or where there is constraint, *e.g.*, from cores which are too rigid; by any non-uniform cold-working process; by re-heating, quenching, riveting; brazing, soldering or welding; and in other ways. In ductile materials, plastic deformation at s. in excess of the yield point value will tend to relieve i.s., but will not reduce those not exceeding this value. The relief of i.s. during machining may lead to considerable distortion of the article. I.s. often play a considerable part in failure, as with season cracking, caustic embrittlement, etc. I.s. can be relieved by a low-temperature annealing appropriate for the alloy in question.

Interrupted Quenching (I. Hardening or Time-Quenching). These processes, which are fundamentally similar, involve quenching with a modified degree of severity, either to avoid the excessive internal stresses sometimes induced by full quenching, or to obtain special properties, the process being sometimes tantamount to hardening and tempering in one operation. In one method, used to eliminate almost entirely the incidence of quenching stresses in the water-hardening of tools of intricate shape and varying section, the tool is cooled rapidly in water to about 400°C ., when the glow disappears, and is then cooled slowly in oil. In another method, the part is quenched in oil for a pre-determined period, and is then

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allowed to cool to room temperature in air. In axles thus treated, the limited period of immersion in oil suppresses the transformation to a certain depth below the surface. On withdrawal, the residual heat gives rise to tempering at about 600° C., to produce a sorbitic wear-resistant surface layer. In another method, the part is quenched in a medium for a pre-determined period, withdrawn for a definite period, and then replaced in the medium for final cooling; the object being to obtain a structure intermediate between those produced by full quenching in the various media available. *See also Martempering.*

Inverse Annealing. A heat treatment, analogous to **Precipitation Hardening**, applied to cast iron to increase its hardness and strength. (Prop. Std. Defn., A.S.T.M., 1942.)

Inverse or Negative Segregation. An effect in which the outer portions of a cast alloy show a higher proportion of constituents of lower melting point, and the inner portions a higher proportion of those of higher melting point, an effect exactly the opposite of what one would normally expect. The "tin-sweat" of bronzes is an example of i.s., which is shown by alloys having a fairly wide solidifying range and cooled at a rate greater than a certain critical value. It is not shown by alloys solidifying wholly at one temperature. The most probable cause is the forcing of the constituent of lower melting point along minute shrinkage channels to the exterior by means of the pressure of gases released during solidification. The method of pre-solidification, followed by remelting under a suitable cover, is practically sufficient to prevent i.s., even in bronzes with a high phosphorus content.

Ion. An electrically charged atom or group of atoms in solution or in a gas. The normal atom is uncharged, its protons and electrons being equal in number; but electrons may either be lost or gained, producing an inequality in the respective numbers of these constituents. Positively-charged atoms, positive i. or *cations*, are deficient in free electrons. Negatively-charged atoms, negative i. or *anions*, show an excess of these. I. are produced in solution by the *ionization* or electrolytic dissociation of the dissolved substance, *e.g.*, common salt, NaCl, to give equivalent numbers of cations, Na⁺, and anions, Cl⁻. Gaseous i. are produced in gases by electrical discharges, the passage of X-rays, etc.

Ionic Compound. *See Polar C.*

Ionization. *See Ion.*

Ionizing Potential. The amount of energy required to remove an electron completely from the atom. I.p. reaches a maximum in a closed electron shell. Electrons of the same i.p. are said to be at the same energy level. See *Atom, Electronic Structure, Quantum Numbers*, etc.

Iridium. Ir. El. A.W. 193.1; At. No. 77; S.G. 22.42; M. Pt. 2454° C. Steel-grey metal, very hard and brittle, only workable at high temperature, when it can be obtained as rod or wire; highly resistant to corrosion. Occurs native, associated with platinum and other metals of the same group. Obtained as a by-product in the extraction of platinum from residues from electrolytic nickel and copper refineries. The high m. pt. of i. can be considerably reduced by the addition of 7 per cent. of phosphorus, this more fusible alloy being utilized in the form of grains for tipping fountain-pen nibs. Used chiefly as a hardener for platinum, which is very soft when pure. I.-platinum alloys containing 10–25 per cent. i. are used for thermocouples; and for insoluble anodes in electroplating and other processes, including the recovery of metals from waste solutions. The 25 per cent. i. alloy is used for contacts in voltage regulators, high-tension aircraft magnetos, thermostats and relays.

Iron. Fe. El. A.W. 55.84; At. No. 26; S.G. 7.86; M. Pt. 1537° C. Hard greyish-white magnetic metal; rusts in air; a poor conductor of heat and electricity; mechanical properties varying greatly according to the content of other constituents, particularly carbon. Occurs as *hæmatite*, Fe_2O_3 ; *magnetic iron ore* or *magnetite*, Fe_3O_4 ; *siderite*, *chalybite* or *spathic iron ore*, FeCO_3 ; *limonite*, $\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$; *iron pyrites*, FeS_2 , etc. Extracted from its ores—either the natural oxides or those obtained by roasting—by smelting in the blast furnace, the resulting pig or cast iron being converted into steel by the open hearth or Bessemer processes; into wrought iron by the puddling process. Used extensively as cast iron and steel in general constructional work, all kinds of machinery, etc.; also as wrought iron, malleable cast iron, etc.

Irregular. In Powder Metallurgy, the lack of symmetry or irregularity in metal powder particles (A.S.M. Defn.).

Irreversible Reaction. A r. which can proceed only in one direction, as the burning of magnesium in oxygen to oxide. See **Reversible R.**

Irreversible Steels. Steels in which the austenite \rightarrow pearlite transformation on cooling occurs at a temperature so much lower than that of the equivalent transformation on heating that this reverse

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transformation cannot be obtained at or near the same temperature. For example, a 20 per cent. nickel steel on cooling remains non-magnetic until a temperature of about 80°C . is reached. On reheating the magnetic steel, however, it does not lose its magnetism once more until a temperature of about 585°C . is reached. The size of this "hysteresis gap" before a steel can be regarded as irreversible is of course arbitrary. Nickel steels containing between, say, 5 per cent. (gap of about 100°C .) and 25 per cent. of nickel (gap of about 500°C .) may be regarded as irreversible. Steels containing more than about 25 per cent. of nickel suddenly become reversible once more, the gap being only about 50°C .

Isobares. Elements of identical atomic weights but different chemical properties. *See Atom. Cf. Isotopes.*

Isometric System. *See Cubic S.*

Isomorphism. The characteristic, shown by different but chemically similar compounds, of crystallizing in the same form.

Isothermal Reaction. A reaction taking place at constant temperature, as in austempering (q.v.).

Isotopes. Elements having the same nuclear charge or atomic number but different nuclear masses or atomic weights. I. differ only in the number of proton-electron pairs in the nucleus, and, since the usual chemical reactions affect only the free external electrons, i. are chemically identical in all their properties. The spectra of i. are identical, these being also electronic in character. I., having the same atomic number, occupy the same place in the Periodic Table (Isotope = the same place). Natural chlorine (at. wt. 35.46) consists of a mixture of 30 atoms of chlorine of at. wt. 37 to every 100 atoms of chlorine of at. wt. 35. The heavier atom contains two extra neutrons in the nucleus. The greater the total number of neutrons and protons in the nucleus, the greater is the number of stable or temporarily stable arrangements that they can make. It is therefore the elements of higher atomic weight which have more i., and are more likely to be radioactive. I. may be stable, as ^2H , deuterium, or ^{18}O , heavy oxygen; or unstable, as the naturally-occurring radioactive i. produced as intermediate decomposition products of radium and thorium, or the artificially-produced radioactive i. of nearly all the elements produced by atomic bombardment with α -particles, deuterons, protons and neutrons. At least half the elements having an odd atomic number are elements having only one stable i. Thus phosphorus is entirely ^{31}P and aluminium entirely ^{27}Al . *See Atom, Atomic Weight, Periodic Table, etc. Cf. Isobares.*

Isotropic. Of materials having the same properties in all directions. *Cf.* **Anisotropic.**

Izod Test. A standard method of notched-bar testing (q.v.). The test piece is 10 mm. square, notched transversely with a V-cut to a depth of 2 mm. and a root radius of 0.25 mm. An alternative test piece is 0.45 in. in diameter, the notch being as before, 2 mm. now representing only the maximum depth at the middle of the notch. Each of these standard forms requires the same energy to fracture. The test piece is held as a cantilever beam (usually vertical) with the notch at the level of the holding vice, the specimen being broken by a single blow struck by a pendulum weight, carrying a hardened steel striking edge, at a position 22 mm. above and on the same side as the notch, so that the root of the notch is in the region of the tensile beam stress. The energy absorbed in breaking the test piece is determined. This test is suitable only for notched specimens. The formula for converting from I. values in ft.-lb. to Charpy values in m.kg./cm.² in the range of I. values from 15 to 70 ft.-lb. is :

$$C = \frac{I + 10}{4.5}$$

For I. values below about 15 and above about 70 ft.-lb., *C* is less and greater, respectively, than that given by the formula. For further information on I.-Charpy relationships, *see* the Addendum of March, 1942, to B.S.S., 131—1933. *See* **Impact Testing, Notch Sensitivity**, etc.

J

Joint. A union of two or more metal parts. A *welded j.* is one where union is effected by welding. A *mechanical j.* is one where union is effected by mechanical means, and welding is not employed. A *composite j.* is one where welding is one of two or more means used for making the connection (B.S.S. 499—1939).

Jominy End-Quench Test. A t. for determining the hardenability (q.v.) of steel. It consists in heating a standard t. bar, 1 in. in diameter, to the correct hardening temperature, followed by water-quenching of the end face only. Both heating and quenching are carried out in a standard manner, as detailed in A.S.T.M. Tent. Stds. A255—42T. The distance from the quenched end to which hardening is effective to a given degree is determined by hardness measurements along two flat surfaces, 0.015 in. in depth, ground 180° apart along the entire length of the specimen, care being taken to avoid tempering in grinding. Rockwell C hardness t. are made at $\frac{1}{16}$ in. intervals for a distance of 2 in. from the quenched end along lines down the middle of each of these flats. The results are plotted on a standard hardenability chart, in which the ordinates are the hardness values and the abscissæ the respective distances from the quenched end. The hardenability of a steel may be designated by a code indicating the distance from the quenched end within which the hardness is greater than the minimum acceptable. Thus, for a steel of 0.35 per cent. carbon content which hardened above Rockwell C50 to $1\frac{1}{2}$ in. ($\frac{24}{16}$ in.) from the quenched end, the Index of Hardenability can be numerically expressed as

$$J_{50} = 24 \text{ (Sixteenths).}$$

Jumping-Up. See Upsetting.

K

Kathode. *See* Cathode.

Killed Steel (or Dead S.). *See* Killing.

Killing. A process of treating molten steel in a furnace, crucible or ladle by the addition of a suitable deoxidizer (*e.g.*, silicon, manganese, aluminium or titanium), to prevent gas evolution in the mould, resulting in an unsound ingot. Steel incompletely deoxidized still contains ferrous oxide (FeO), which reacts with the carbon in solution to give rise to carbon monoxide gas during solidification, the excessive evolution of gas causing the steel to be "wild" or "fiery". The deoxidizing addition (*e.g.*, silicon to 0.12, or aluminium to 0.02 per cent.) gives rise to an inert oxide (SiO_2 or Al_2O_3), which does not react with the carbon, killed steel thus remaining quiet in the mould. The ingot is therefore comparatively solid; showing, however, a marked shrinkage effect, taking the form of a well-defined central cavity or pipe. A greater discard from the top of the ingot is thus necessary, the usable portion is smaller and the steel therefore more costly, being used for more important duties, *e.g.*, boiler plates. *Cf.* Semi-Killed and Rimming Steel.

Kinking. *See* Stretcher Strains.

Kish. A form of light crystalline graphite occurring on the surface of molten cast iron containing more than 4.3 per cent. of carbon, resulting from the separation of iron carbide (Fe_3C), and its simultaneous decomposition into iron and carbon.

L

Labile Equilibrium. See **Metastable E.**

Lamellar (or Laminated). Disposed in layers or thin plates, as those of ferrite and cementite in pearlite.

Lanthanum. La. El. A.W. 138.92; At. No. 57; S.G. 6.12; M. Pt. 810° C. White "rare earth" metal. Occurs in *monazite sand*. Obtained in a state of 99.86 per cent. purity by electrolysis of the fused chloride, LaCl_3 . Used as a constituent in aluminium and other alloys with fairly promising results, but further research is necessary.

Lanz Perlit Iron. A special cast i. produced by pouring into a sand mould, heated to a pre-determined temperature, a low-silicon and preferably low-carbon basis i. of pre-determined composition. The basis i. would normally give rise to white or mottled castings, but, by means of a suitable balance between composition and mould temperature, the separation of a controlled quantity of finely-dispersed graphite can be effected, so as to give rise to an i. of high tensile strength, 20–22 tons per sq. in., and of consistent quality in light and heavy sections alike. This is because the tendency to graphitization in the heavy sections—where the effect of heat from the mould walls, in relation to the mass of the metal, is less—is diminished by using a low silicon content. The tendency to graphitization in the light sections is increased by the action of the hot mould walls in close proximity to each other. Thus the mould temperature regulates graphitization in the light sections, and the silicon content that in the heavy ones. The slow and controlled cooling ensured by casting in a hot mould also avoids the setting up of contraction stresses such as are inseparable from casting in a cold mould.

Lap. A longitudinal surface defect in rolled and sometimes in forged steel, due to the section overfilling a previous roll-pass, or to the bending over and rolling in of a flash (or fin), ridge or other elevation; so that surface scale is enclosed in the fold, and the metal is not properly jointed, the resulting defect extending longitudinally on further working. As distinct from a roke (q.v.), a l. therefore runs obliquely into the steel, and not, as with a roke, directly towards the centre. The layer of oxide scale enclosed in a l. is usually found to separate two layers of ferrite, representing the decarburized

original surface. If present in the finished article, a l. is a dangerous source of weakness.

Latent Heat (or Heat Equivalent) of Fusion. The quantity of heat required to convert unit mass of a solid into liquid without change of temperature. In c.g.s. units, it is the number of gram calories required to convert 1 gm. of substance from solid into liquid at the same temperature, *i.e.*, that of the m. pt.

Latent Heat of Vaporization. The quantity of heat required to convert unit mass of a substance from liquid into vapour without change of temperature. In c.g.s. units, it is the number of gram calories required to convert 1 gm. of liquid into vapour without change of temperature.

Lattice (Space L.). The regular periodical spacial arrangement in three dimensions of the atoms constituting the structural units of crystals of solid metals and alloys. Those in which metals more commonly crystallize are : (1) *The face-centred cubic l.*, in which the unit cell has 8 atoms at the cube corners, and 6 atoms, one at the centre of each cube face. Each atom has thus 12 equidistant neighbours ; or, if the atom be regarded as a sphere, each is in contact with 12 others, representing the closest possible packing. Shown by aluminium, copper, lead, platinum, gold and silver, and by one modification of iron, cobalt and nickel. (2) *The body-centred cubic l.*, where the unit cell has an atom at each cube corner and one at the centre of the cube. Each atom has thus 8 equidistant neighbours, or, regarding the atom as a sphere, is in contact with 8 others, representing a looser degree of packing than with the face-centred cubic l. Shown by molybdenum and vanadium ; and one modification of iron, chromium and tungsten. (3) *The close-packed hexagonal l.*, where the atoms are arranged on a hexagonal prism, composed of six triangular prisms, of height normally $\sqrt{\frac{8}{3}}$ or 1.633 times the edge of the base. In the hexagonal prism, there is an atom at each corner, and one at the centre of alternate triangular prisms. Each atom has 12 equidistant neighbours ; or, regarding the atom as a sphere, is in contact with 12 others, representing the hexagonal closest packing of spheres. The axial ratio may not be exactly 1.633, when the 12 neighbours occur in two sets of 6, at slightly different distances. Shown by beryllium, cadmium, magnesium and zinc ; and one modification of chromium, cobalt and nickel. (4) *The face-centred tetragonal l.* resembles the face-centred cubic l., but one axis is longer or shorter than the other two. Shown by one modification of tin (white tin) and of manganese.

Lea

(5) *The rhombohedral hexagonal l.*, in which the atoms are arranged in double layers so that each has 3 close neighbours and 3 at a distance slightly greater. Shown by arsenic, antimony and bismuth. Other metals show more complex l. structures. See also **X-Ray Crystal Analysis**.

Lead. Pb. El. A.W. 207·21; At. No. 82; S.G. 11·37; M. Pt. 327° C. Bluish-grey metal, very soft and malleable. Clean surface shows a metallic lustre, which soon disappears on exposure to air; very resistant to corrosion. Occurs chiefly as *galena*, PbS; also as *cerussite*, PbCO₃; *anglesite*, PbSO₄, etc. Extracted by roasting galena in an oxidizing atmosphere, when a mixture of oxide and sulphate results; on shutting off the air, raising the temperature, and adding quicklime, the residual sulphide largely reacts with the two oxidized products to produce the metal, which is then refined. Used as pipe for domestic water supply, sheet for roofing purposes, storage batteries, cable sheathing, ammunition, and for many purposes in chemical plant, where its corrosion resistance is increased still further by small additions of other metals, as copper, nickel and tellurium. L. coatings, applied by hot dip or electroplating, replace those of zinc for rust-proofing iron and steel. Ternary l. alloys, containing 0·25 per cent. of cadmium; and, alternatively, either 0·5 per cent. of antimony or 1·5 per cent. of tin, have in either case a strength about twice that of pure l., so that a substantial reduction in weight of pipe and sheet for various purposes can be effected. L. containing 0·05 per cent. of tellurium has, for the same strength, a higher ductility and a greater resistance to recrystallization than either pure l., or l. containing 1–3 per cent. of tin, the l.-tellurium alloys, used for cable sheathing, being fine-grained, very resistant to vibration and more amenable than pure l. to extrusion. L. hardened with tin and antimony forms an important series of bearing alloys; as also do those hardened by means of barium and calcium. L. is a major constituent in solders. The 30 : 70 l.-copper alloy is used for connecting rod big-end bearings in petrol and oil engines. As an addition to the extent of about 0·25 per cent. in steel, l. much improves machinability without detriment to mechanical quality. There are various other uses.

Ledeburite. The eutectic containing, by weight, 48 per cent. of saturated austenite (1·70 per cent. carbon) and 52 per cent. of cementite, formed at about 1130° C. by the rapid cooling of white cast iron during or just below the freezing point. In cooling, the austenite in l. transforms to ferrite and cementite. L. is also found in high-alloy steels, e.g., high-speed steel.

Life. See **Flowing Power**.

Limit of Proportionality. *See* Proportionality Limit.

Limiting Creep Stress. The maximum s. at which a material will not c. by more than a certain amount within the working life of the part. Such "permitted c." must naturally vary with the duty of the part in question, and its relation with the duties of associated parts. The term has sometimes been defined as the s. to which the particular steel may be subjected at any temperature without exceeding an elongation of 10^{-5} in. per in. per day. Such a rate of c. is, however, greater than could often be tolerated in practice, and the definition first given is thus more correct. Permissible c. rates for various parts in service are approximately as follows: Turbine rotor wheels shrunk on to shafts, 10^{-9} per hour; turbine solid rotors, bolted flanges, turbine cylinders, 10^{-8} per hour; steam piping, welded joints, boiler tubes, 10^{-7} per hour; superheater tubes, 10^{-6} to 10^{-5} per hour.

Line Spectrum. *See* S.

Lineage Structure. A crystal s. growing from a single centre, but showing, instead of the perfectly regular lattice arrangement of an ideal crystal, a lattice which is a little deformed, the dendritic branches, instead of being parallel, being very slightly inclined to each other, so that different parts of the crystal show small differences in orientation. These slightly inclined branches are known as lineages, a crystal being thus made up of a number of l. developing from a single nucleus. The lack of parallelism may be due to small variations in the conditions during growth, or local distortion caused by foreign atoms in solid solution. A cross-section through such a s. would show a mosaic s. (q.v.), affording an alternative explanation for this effect.

Link (or Linkage). *See* Bond.

Liquation. (1) Strictly, the heating of a solid mixture so that the more readily fusible constituent melts, and a separation can thus be effected. (2) The term is sometimes used to denote the exudation of drops of liquid metal through the outer crust of a solidifying mass, as with "tin sweat" (q.v.). The exuded portion is a more fusible constituent of the alloy, and may be the almost pure eutectic, if one is present.

Liquid. A substance which undergoes continuous deformation when subjected to shearing stress. A simple liquid is one in which the rate of shear is proportional to the shearing stress. The constant ratio of shearing stress to rate of shear of a simple liquid is the

Liq

viscosity of the liquid. A complex liquid is one in which the rate of shear is not proportional to the shearing stress. *Cf.* Solid. (A.S.T.M. Stds., E24—42.)

Liquidity. *See* Flowing Power.

Liquidus, Liquidus Curve or Freezing-Point Curve. In a constitutional or equilibrium diagram, the lines indicating the temperatures above which all alloys in the system are completely liquid. *Cf.* Solidus.

Lithium. Li. El. A.W. 6.94; At. No. 3; S.G. 0.534; M. Pt. 180° C. Silver-white alkali metal, the lightest metal known. Occurs as *spodumene* ($\text{Li}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 4\text{SiO}_2$), *amblygonite* ($\text{Li}(\text{AlF})\text{PO}_4$) and other minerals. Extracted by a wet process involving precipitation as carbonate, the metal being finally obtained by electrolysis of the fused chloride, bromide or cyanide, in a state of 99.5–99.7 per cent. purity. L. is used as a l.-calcium alloy (50 : 50 or 30 : 70) for the deoxidation of copper and bronzes; as a hardener in lead bearing alloys (*e.g.*, Bahnmetail), and in silver solders, to promote fluidity, wetting, tensile and cross-breaking strength, particularly on large brazed sections. L. is also used as a hardener in 18:8 stainless steels.

Load-Extension Diagram. A diagram, applying usually to tensile loading, plotted with loads as ordinates and increases in gauge length as abscissæ, thus relating load to extension of the material, and showing the values for proportionality limit, yield point and ultimate stress before fracture. It should be noted that the values are nominal and not actual, for they are calculated in reference to the original and not to the deformed cross-sectional area. Again, with a ductile material, as mild steel, by reason of the "necking down" and consequent reduction of area which occurs before fracture, the test piece can be broken by a load decidedly lower than the maximum load shown by the machine. The actual stress intensity in the test bar is of course a maximum at fracture, and can be determined by relating the minimum load capable of producing fracture to the reduced area at the fracture; a relation which cannot readily be determined in the usual commercial testing. *See also* Stress-Strain Diagram and True Tensile Stress.

Locked-Up Stresses. *See* Internal Stresses.

Lubricating. In Powder Metallurgy, mixing with, or incorporating in a powder, some agent to facilitate pressing (A.S.M. Defn.).

Lüders Lines. *See* **Stretcher Strains.**

Luminescence. The radiation from a body, at low temperature, of light which does not result from the absorption of radiant energy (as heat or light). L. is shown by the freshly-cut surfaces of sodium and potassium, and by certain living organisms. *Cf.* **Chemiluminescence and Phosphorescence.**

M

M.B.V. Process. A protective surface treatment for aluminium and its alloys, involving immersion in an aqueous solution of anhydrous sodium carbonate (5 per cent.) and anhydrous sodium chromate (1.5 per cent.) at a temperature of 90–100° C. for 3–5 minutes, followed by washing in hot or cold water. The colour of the film produced varies from light to dark grey. It is very elastic and adherent, cannot be detached by folding, rolling or pressure; and, although its mechanical resistance is not exceptionally high, it has a very protective effect against corrosion.

Machinability. That quality of a metal or alloy which enables it to be readily shaped by cutting tools, with the production of a smooth surface. One factor influencing m. is hardness, but the structure also plays a great part. Thus metals, and alloys composed of a single solid solution, are usually very ductile, so that they deform and flow under the tool pressure, and thus tend to drag and tear instead of shearing off smoothly. M. is then greatly improved by the presence of a second dispersed phase, as lead in α -brass, giving rise to "free-cutting" brass. Again, low-carbon steel low in pearlite is a very ductile material, and its m. can be much improved by the presence of a second dispersed phase, as sulphide inclusions, particularly when these are associated with a banded structure. Alternatively, the processes of quenching or cold-working, to embrittle the material and reduce its ductility, will often greatly improve m. The austenitic steels constitute, however, an exception, in that work-hardening gives rise to martensite, considerably reducing m. It is therefore essential, with these steels, to use a sharp tool and to avoid "rubbing". The excellent m. of grey cast iron, enabling it to be cut without a lubricant, is due to the presence of the brittle flakes of graphite, which break up the continuity of the metal and lead to continuous local fracture under the stresses operating.

Macrograph. A graphic reproduction of any object which has not been magnified more than 10 diameters. When it is desired to indicate that it is a photographic reproduction, the term "photo-macrograph" may be employed. (A.S.T.M. Std. Defn. E7—27.)

Macrography. The study of macrostructures (q.v.).

Macroscopic. Visible either to the naked eye or under low magnifications (up to about 10 diameters) (A.S.M. Defn.).

Mag

Macrostructure. The general structural distribution or "gross" structure of a metal or alloy, as revealed on a sample which has been polished and then deeply etched, when examined either by the naked eye, or under very low magnification. It is the structure as a whole, as distinct from the microstructure, which is that of a minute area only. The m. is governed by the conditions of solidification and of the subsequent working. Thus the crystal structure of a cast alloy or the "flow lines" of a steel forging are determined most readily by examination of the m., which may also reveal the presence of hair-line cracks or other defects previously unobservable. Sulphur printing, showing the distribution of sulphide particles, is one indication of m. See also **Dendrite**, **Flow Lines**, **Ingotism**, etc.

Magnafluxing. See **Magnetic Testing**.

Magnesium. Mg. El. A.W. 24.32; At. No. 12; S.G. 1.74; M. Pt. 651° C. Very light silvery-white metal, workable only by a special technique, when it can be forged, extruded, etc.; unaffected by dry air but readily attacked by moist air. Burns in air with a brilliant white light when ignited. Occurs as *magnesite*, MgCO_3 ; *dolomite*, $\text{MgCO}_3 \cdot \text{CaCO}_3$; *carnallite*, $\text{KCl} \cdot \text{MgCl}_2 \cdot 6\text{H}_2\text{O}$; *Epsom salts*, $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$, many other minerals, sea water, etc. Extracted by the electrolysis of fused m. chloride or carnallite, or by reduction of the oxide with carbon or silicon, and distillation and condensation of the reduced metal. Used in the radio industry for de-gassing valves; as a deoxidizer in copper, brass and nickel alloys; mixed with potassium chlorate or barium peroxide, as a flash powder used in photography, for star shells, incendiary bombs, etc. Magnesium-base alloys, as Elektron, Dow Metal, etc., where the chief alloying elements—usually not exceeding 10–12 per cent.—are manganese, aluminium and zinc, have enormous application in the aircraft industry as forgings, castings, etc. M. is also an essential constituent in aluminium and zinc-base alloys, to impart special properties, facilitate heat treatment, etc.

Magnetic Change Point. See **Curie P.**

Magnetic Testing. An inspection procedure in which the steel part is suitably magnetized, and then a medium is applied to reveal the presence of grinding or other cracks, sub-surface seams and similar defects. Magnetization may be either by alternating or direct current, and may either be continuous—the medium being applied simultaneously—or the residual method may be used; this relying upon the magnetic retentivity of the material for the indication. The medium is a finely-divided ferromagnetic material,

Mag

applied either as a dry powder ; or as a suspension in a liquid, such as a light oil distillate. If the flux field includes a crack, each side of this becomes a magnetic pole, causing the indicator to collect locally, and thus to delimit the defect. By more intense magnetization the flow lines of the material can be developed. Magnafluxing is the proprietary name of one process of m.t.

Magnification. The ratio of the size of the image to that of the object. Magnification is generally expressed in diameters, thus " $\times 100$ " or " 100 diameters ". (A.S.T.M. Std. Defn. E7—27.)

Malleability. The property enabling a material to be compressively deformed without rupture ; as in hammering or rolling.

Malleable Cast Iron. Iron white as cast (when the carbon is present entirely in the combined state) which has been made malleable by an after-process of annealing, when the combined carbon is converted into temper carbon or graphite, separating not in thin flakes, as in ordinary grey iron, but as rounded nodules or rosettes. Compared with their masses, the surface areas of these inclusions are very small, and they therefore break up the continuity of the metal to a correspondingly lesser degree, such material having a limited ductility, enabling it to be used where ordinary cast iron is unsuitable, although it is not malleable in the sense which this term really implies. There are two variations of the process, the Réaumur or "European" process (Whiteheart M.), and the "American" process (Blackheart M.). In the Whiteheart process, the castings are embedded in hæmatite iron ore and heated for several days at a temperature of 900° – 950° C., being then cooled very slowly. The carbon is not only very largely converted into graphite, but this is also to a great extent burnt away. Thus thin sections, and the external layers of thick sections, become entirely ferritic, the inner portions of the last showing a steel-like structure of mixed ferrite and pearlite, with some graphite. In the Blackheart process, the castings are annealed at a lower temperature (750° – 850° C.) in an inert packing, so that little oxidation occurs, except at the outer edges of the casting, while the core is very dark, due to the conversion of all the combined carbon into graphite, the annealed structure thus consisting of ferrite and graphite. Whiteheart M. is a little stronger but rather less ductile than Blackheart. Both processes are commonly used to-day in this country. Each has its own advantages and defects for the varying requirements of service. *See also Short Cycle Annealing.*

Malleable Iron. *See Wrought Iron.*

Malleablizing. A process of annealing white cast iron in which the combined carbon is wholly or in part transformed to graphitic or free carbon, and, in some cases, part of the carbon is removed completely. (*See also Temper Carbon.*) (Prop. Std. Defn., A.S.T.M., 1942.)

Manganese. Mn. El. A.W. 54.93; At. No. 25; S.G. 8.0; M. Pt. 1242° C. Greyish-white or reddish-white hard and brittle metal. Occurs as *pyrolusite*, MnO_2 ; *braunite*, Mn_2O_3 ; *hausmannite*, Mn_3O_4 ; *manganite*, $\text{Mn}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$, and other minerals. Extracted by reducing the oxide either with carbon in the electric furnace or by the thermit process. By electrolysis a concentrated solution of manganous chloride, using a mercury cathode, followed by vacuum distillation of the mercury at 250° C., the purest m. is obtained. The metal itself has no applications, but m. is much used as an alloy. As spiegel or ferro-manganese, it is used, in a proportion of some 0.5–0.6 per cent., as a deoxidizer of molten steel, to remove ferrous oxide, which would render the finished steel hot-short and unworkable; and also to replace harmful iron sulphide by innocuous m. sulphide (*see Sulphur*). In higher proportion, about 1.5 per cent., m. gives rise to pearlitic m. steel, of mechanical quality superior to that of mild steel, and intermediate between that of mild steel and 3 per cent. nickel steel. In a similar proportion, but with some 0.2–0.4 per cent. of molybdenum, steel of quality approximating closely to 3 per cent. nickel steel is obtained. The so-called M. Steel (q.v.) contains a much higher proportion of manganese. In cast iron, m. is a corrective against sulphur, and lowers and prolongs the freezing range, thus promoting sound castings. M. is also used in non-ferrous alloys, e.g., m. bronze, aluminium alloys, magnesium alloys, etc.

“Manganese Bronze”. This alloy is not a true bronze, as it contains little or no tin, and its designation is merely a matter of trade custom. It is actually a high-tensile brass (q.v.), with an approximate range of composition as follows: Copper, 56–63 per cent.; manganese, 2.5 per cent. (max.); aluminium, 5.0 per cent. (max.); iron, 2.0 per cent. (max.); tin, 0.5 per cent. (max.); zinc the remainder. In the cast state such alloys will readily show a tensile strength of 30 tons per sq. in., with 30 per cent. elongation, a mechanical quality equal to that of mild steel, associated with much greater corrosion resistance; while, by increasing the proportion of alloy constituents, values of 40 tons per sq. in. and 20 per cent. elongation are obtained. The alloys are also readily forged, when the mechanical quality is likewise excellent. M.b. is thus used extensively for propellers, rudders and other ship's fittings, gun mountings and a number of other engineering purposes requiring

Man

a strong non-corrodible alloy. The m.b. casting alloys are either $\alpha + \beta$ or full β -brasses, according to the intended purpose. For propellers, for example, an $\alpha + \beta$ structure is more suitable for a long narrow-bladed slow-speed impeller running at 85 r.p.m.; while an all- β structure is more suitable for a short wide-blade high-speed impeller running at 350 r.p.m., where a much "stiffer" alloy is required. See also Brass.

Manganese Steel. As has already been shown, under *Manganese*, this metal is used in low proportion as a deoxidizer in all steels, while the pearlitic m. steels depend for their mechanical properties largely upon higher proportions of m., of about 1.5 per cent. In general usage, however, the term refers to high-m. steel, containing some 11-14 per cent. of m., with 1.0-1.3 per cent. of carbon, a steel originally known, from its discoverer, as Hadfield's M.S. This s., when water-quenched from 1000° C., is completely austenitic and soft. The austenite, however, is mechanically unstable; and, when subjected to processes of crushing, cutting, and the like, the surface layers are converted into martensite, which is intensely hard, but the interior portions remain soft and tough. M.s. is thus eminently suitable for the manufacture of rail and tramway points and crossings, crushing machinery, etc.

Martempering. A heat-treatment process for steel, in which martensite is produced with a minimum of residual hardening stresses. M. embodies a short-period intensive quench, transfer to a liquid bath at high temperature, the equalization of temperature throughout the part by holding in this for a sufficient period, cooling in air to normal temperature, and, finally, the required tempering, varying with the steel and the dimensions of the part being treated. M. thus differs from austempering (q.v.), which specifically avoids the production of martensite with this type of quench. See also *Interrupted Quenching*.

Martensite. A decomposition product of austenite, and the hard constituent (Brinell H. up to 800) of quenched steels. When the cooling rate is sufficiently rapid, the austenite \rightarrow pearlite transformation is suppressed, and m. is produced at a much lower temperature, varying with the carbon content, and sometimes below 100° C. With steels of higher carbon content, some austenite may be retained on quenching. M. consists of a supersaturated solution of carbon (or Fe_3C) in highly-stressed α -iron, and contains varying proportions of carbon, up to about 1.8 per cent. It is magnetic and frequently characterized by an acicular pattern, the needles of which often show an arrangement in three systems intersecting at 60°, marking the cleavage planes of the original austenite. Two

varieties have been recognized, α -m., having a body-centred tetragonal lattice, obtained by drastic quenching to below $100^{\circ}\text{C}.$; and β -m., having a body-centred cubic lattice, resulting on tempering α -m. at temperatures between 100° – $170^{\circ}\text{C}.$ β -m. is softer than α -m., but the annealing gives rise to no real change in the microstructure.

Martensitic Cast Irons, resistant to wear and abrasion, can be obtained by suitable quenching and tempering of ordinary c.i. (much as with steels); or may alternatively be produced on slow cooling by the use of suitable alloy additions (*e.g.*, 5–7 per cent. of nickel), which have the same effect as a more rapid cooling. There are two classes of m.c.i., one harder (Brinell hardness 550–700), in which the carbide of the eutectic is unchanged; and one softer (Brinell hardness 350–450), in which the carbide of the eutectic has decomposed into graphite.

Mass Defect. *See Atomic Weights.*

Matrix (or **Groundmass**). In a heterogeneous aggregate, the principal constituent, in which other constituents are embedded.

Matrix Metal. In Powder Metallurgy, the lower melting-point metallic constituent of a powder mixture which melts during the sintering operation and functions as a cementing medium (A.S.M. Defn.).

Maximum Shear Theory (Guest). A t., advanced as a criterion of failure, in which fatigue failure is considered to be determined by a constant value of the greatest difference of principal stresses. Shear stresses occur, not on principal planes, but on planes intermediate between these. The intensity of the maximum shear stress thus determined is equal to half the greatest difference between the principal stresses.

Maximum-Strain Theory (St. Venant). A t., advanced as a criterion of failure, assuming that elastic failure takes place when the maximum principal strain exceeds a limiting value for the material. The t. assumes that, when a material is subjected to two or three stresses at right angles to one another, the strength is reduced if the stresses are opposite in sign, and increased if they are of the same sign. It does not hold for ductile materials.

Maximum Stress. *See Ultimate S.*

Max

Maximum-Stress Theory (Rankine). A t., advanced as a criterion of failure, assuming that elastic failure takes place when the maximum principal stress exceeds a limiting value for the material, irrespective of the intensity of the stresses on the other principal planes. This t. assumes that a second stress, at right angles to the first, neither weakens nor enhances the original stress. It does not hold for ductile materials.

McQuaid-Ehn Test. A method of grain-size testing as a check on the uniformity of mild steels. Micro-sections are heated at 1700° F. (927° C.) in a solid carburizer for at least 8 hours; and cooled slowly so as to develop a cementite network round the former austenite grain boundaries. The sample is then photographed at a magnification of 100 diameters and compared with a grain-size chart issued by the A.S.T.M. (Spec. E19—39T), discussed under *Grain Size*. This arbitrary method obviously affords a measure of austenite coarsening during carburizing, but affords no indication of its behaviour under entirely different conditions.

Mechanical Hysteresis. In an imperfectly elastic material, the lagging of strain behind the stress giving rise to it.

Mechanical Hysteresis Loss. See *Damping Capacity*.

Mechanical Refining. Grain refinement by hot working (q.v.), as by the hammer or press.

Mechanical Working. Subjecting metal to pressure exerted by rolls, presses or hammers, to change its form, or to affect the structure and therefore the physical properties (A.S.M. Defn.).

Medium-Carbon Steel. S. containing between about 0.3 and 0.6 per cent. of c. No sharp line of demarcation between M.-C. S. and Mild S.; or M.-C. S. and High-C. S., is universally recognized.

Meehanite. See *Inoculated Cast Irons*.

Melt. (1) To fuse or liquefy. (2) A heat or charge of steel or other metal or alloy.

Melting, Latent Heat of. See *Latent Heat of Fusion*.

Melting Point. The constant temperature at which a substance changes from the solid to the liquid state. Pure metals, eutectic alloys and many intermetallic compounds have a definite m. pt.

Other alloys melt over a range of temperature, during which they are partly solid and partly liquid.

Melting-Point Curve. See Solidus.

Mercury. Hg. El. A.W. 200.61; At. No. 80; S.G. 13.56; M. Pt. — 39° C. Silver-white metal, the only one liquid at ordinary temperatures. Occurs native in small quantities, but chiefly as *cinnabar* (HgS). Extracted by roasting, when the sulphur is burnt off as sulphur dioxide; or by heating with lime in closed retorts, when the sulphur is removed as calcium sulphide. The liberated m. is distilled over and condensed. In another method, the ore is dissolved in alkaline sodium sulphide, and the m. precipitated by adding aluminium turnings. Used in scientific and electrical apparatus, m. vapour lamps, the m. boiler, the m.-arc rectifier, and the amalgamation process for recovering gold and silver; as an alloy, in soft solders and dental alloys or *amalgams* (q.v.).

Merit, Figure of. See Figure of Merit.

Mesh. In Powder Metallurgy, the screen number of the finest screen of a specified standard screen scale through which all of the particles of a powder sample will pass. Frequently, but not necessarily, a part of the sample may pass finer screens. *Mesh Fraction* is that part of a metal powder passing a specified mesh screen and retained by some finer stated mesh. *Minus Mesh* or *Through* is the portion of a powder sample which passes through a stated screen. *Plus Mesh* or *Oversize* is the portion of a powder sample retained on a screen of stated size. (A.S.M. Defns. in all four cases.)

Metal. Any of the metallic elements, either of very high purity or of ordinary commercial grades. Brass and many other alloys are metals in the commercial sense, but alloys in the scientific sense. (A.S.T.M. Std. Defn. E7—27.)

Metal Ceramics. See Powder Metallurgy.

Metal Powder. Discrete metal particles of small size, generally less than 0.01 in. along their greatest dimension. Such p. is not usually produced mechanically, as by grinding, crushing or disintegration. The metals first produced in this form, and those still so produced in greatest amount—as tungsten, molybdenum and copper—are obtained directly as p. by the reduction of metallic oxides or salts; or by electrolysis. Iron p. is produced by reduction direct from the ore. The designation sometimes found, “powdered metals”, is thus quite erroneous.

Met

Metal-Spraying (or Metallization). The process of coating with a metal by means of a spray composed of a large number of "atomized" particles, projected, by means of compressed air, from a "pistol". This is automatically fed with wire heated in an oxygen blowpipe flame, the small molten globule at the end of the wire being continuously "atomized". Any metal obtainable in wire form can thus be sprayed, and a later development of the process uses metals in the form of powder instead of wire. Among applications are the zinc-s. of iron and steel parts for rust-proofing, the s. of aluminium on parts exposed to high temperatures, the s. of tin on the surfaces of food containers, etc.

Metallization. See Metal-Spraying.

Metallography. That branch of science which relates to the constitution and structure, and their relation to the properties, of metals and alloys. (A.S.T.M. Std. Defn. E7—27.)

Metallurgy. (1) The extraction of metals from their ores, refining them and adapting them for use in manufacture; these processes being now often covered by the term, "Chemical M.". (2) Physical M., or Metallography (q.v.).

Metastable Equilibrium. The condition of a material which is not in a state of complete physico-chemical e. Hardened steel and many industrial alloys are used in such a state. M.e. is exhibited by a super-cooled liquid, *i.e.*, one which remains liquid below its true freezing point. A cooling liquid can be caused to solidify at its true freezing point by the addition of nuclei of the solid phase which is about to solidify. If the liquid is cooled and kept well stirred, solidification occurs at a definite temperature, which, however, is lower than the true freezing point. In the interval between these two temperatures, the liquid is said to be in a state of m.e. Such solidification leads to a sudden liberation of heat, causing the temperature to rise once more, this effect being known as *recalcescence*. Below the m. region, solidification occurs spontaneously on stirring. If the liquid is not stirred, solidification may be delayed still further, particularly if the temperature is rapidly reduced. If the material remains liquid below the m. limit, it is said to be in a state of *labile e.*

Micrograph. A graphic reproduction of any object magnified more than 10 diameters. When it is desired to indicate that it is a photographic reproduction, the term "photomicrograph" may be employed. (A.S.T.M. Std. Defn. E7—27.)

Micrography. The study of metal structures under the microscope.

Micron. 0.001 mm., or 0.000039 in.

Microstructure. The fine or detail-structure of a metal or alloy, as developed by suitable polishing and etching, followed by examination under the microscope at a magnification of usually not less than 20 diameters, and frequently much greater. The m. shows the different phases making up the material, any non-metallic inclusions which may be present, and numerous other features; thus constituting an essential part of the study of metals and alloys. *See* **Polishing, Polish Attack, Etching, Heat Tinting**, etc. *Cf.* **Macrostructure**.

Mild Steel. S. containing carbon not in excess of about 0.3 per cent. No sharp line of demarcation between M.S. and Medium-Carbon S. is universally recognized.

Milling. In Powder Metallurgy, the mechanical treatment of metal powder or metal powder mixtures, as in a ball mill, to affect the size or shape of the individual particles, or to coat one component of the mixture with another (A.S.M. Defn.).

Mixed Crystals (German *Mischkrystalle*). A solid solution (q.v.); and not, as might be supposed, a mixture of crystals, or heterogeneous aggregate. The term is therefore confusing and redundant.

Mixing (or **Blending**). In Powder Metallurgy, the thorough intermingling of particles of two or more powders (A.S.M. Defn.).

Modulus of Elasticity. *See* **Elastic Modulus**.

Modulus of Rigidity. *See* **Elastic Modulus**.

Modulus of Transverse Rupture. *See* **Transverse Test**.

Molecular Composition. In an alloy, the number of molecules of a metal present in 100 molecules of the alloy. *Cf.* **Atomic C.**

Molecule. The smallest particle of a substance which can exist by itself and still possess the properties characteristic of the original substance. The m. consists of an aggregate of still smaller particles, known as *atoms* (q.v.), electrically united. The m. of an element consists of a fixed and usually small number of its atoms. The m. of a chemical compound consists of a fixed number of one or more

Mol

atoms of each of its several elements, their arrangement determining the properties of the compound.

Molybdenum. Mo. El. A.W. 95.95; At. No. 42; S.G. 9.01; M. Pt. 2500° C. A dull-silver malleable metal, unaffected by exposure to air, but oxidizing slowly at 600° C.; a good conductor of electricity. Occurs as *molybdenite*, MoS_2 , *wulfenite*, PbMoO_4 , and other minerals. Obtained as a grey powder by reducing the trioxide, MoO_3 (obtained by volatilization from the roasted sulphide ore), with aluminium or hydrogen. The powder is pressed into bars, sintered, swaged and drawn into wire. Used as supporting filaments in electric lamps and radio tubes, and as a resistor for electric furnaces; where, however, it must be surrounded by an inert gas or suitable refractory. Employed chiefly as an alloy in steel, to increase strength and hardness (manganese-m. steels); to reduce temper brittleness (nickel-chrome-m. steels); increase creep resistance (carbon-m. and nickel-chrome-m. steels); maintain hardness at high working temperatures (high-speed steels, where m. can replace some of the tungsten) and for various other purposes. In cast iron, m. increases strength and resistance to temperature. M. is also a constituent of various hard and corrosion-resistant alloys; e.g., for tipping pen nibs, the manufacture of chemical apparatus, etc.

Monotectic. A eutectic in which the quantity of one phase is infinitely small. In the cooling of an alloy where the liquidus slopes continuously from the melting point of one metal (or compound) to that of another, and the solidus is a horizontal line at the melting point of the more fusible of the two metals (or compounds), the phase separating at the solidus temperature.

Monotron Hardness Test determines the load in kilograms required to make in the specimen an impression of arbitrary size, viz., 0.045 mm. deep and 0.33 mm. in diameter, the load being a measure of the hardness. The instrument is fitted with two dials, one registering the standard depth of impression and the other the load required to produce this. Alternatively, of course, the instrument can be used to determine the depth of penetration for any given load. The deformation determined is partly elastic and partly plastic.

Mosaic Fragments. The mosaic of much smaller crystal fragments, with different orientations, resulting from plastic deformation, by cold working, of an aggregate of crystals. *See also Crystallites.*

Mosaic Structure. A comparatively large-scale secondary structure, superimposed upon the regular atomic arrangement in a

crystal. Its existence is postulated in order to explain some characteristics of crystal structure (*e.g.*, the spacing of slip planes in the earlier stages of deformation, and the regular etch figures that may be produced by chemical attack) which seem incompatible with a perfect lattice arrangement, but can be expressed on the basis of the existence of a m.s., coarser than the atomic lattice but much finer than that of the crystals themselves. Thus a crystal may consist of a number of smaller blocks of the same size and shape, showing a regular atomic arrangement within the blocks, but an irregular lattice spacing at the boundaries between them. An alternative explanation of this effect is given under **Lineage Structure**, q.v.

Mottled Iron. *See* **Cast Iron**.

Muck Bar. In the manufacture of wrought iron, a bar rolled from a squeezed bloom. (A.S.T.M. Stds., A81—33.)

Muffle Furnace. A closed chamber in which the charge is heated out of contact with the fuel or heating gases.

N

Needles. (1) Elongated crystals, tapering at each end to a fine point, as those typical of martensite (q.v.). (2) In Powder Metallurgy, metal powder particles of elongated form, resembling a needle (A.S.M. Defn.).

Negative Quenching. The mere acceleration of cooling by immersion in water, at a temperature such that no transformation is suppressed or retarded, and no change in physical quality results. Steel may thus conveniently be "quenched" from a black heat.

Negative Segregation. *See Inverse Segregation.*

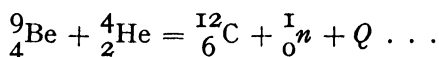
Negatron. The negative electron, usually described simply as the electron (q.v.).

Network Structure. A type of structure—commonly found in steels, cast irons and other alloys—in which a phase, separating from a solid solution, deposits preferentially, but not necessarily entirely, at the crystal boundaries, which are thereby thickened. Hypo-eutectoid steels thus show a n. of ferrite, and hyper-eutectoid steels, one of cementite; affording in either case an indication of the original austenite grain size. In cast iron, the phosphide constituent occurs frequently as a n. round the pearlite grain boundaries. *See also McQuaid-Ehn Test, Sub-Boundary Structure, etc.*

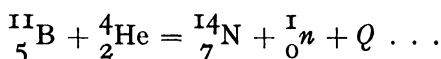
Neumann Bands. A particular type of twinning in α -iron (ferrite) which has suffered sudden deformation, as from shock or impact, and shown as narrow lines or bands, which may either be straight or curved, and are related geometrically to the crystal lattice.

Neutrino. A supposed nuclear particle with small mass, no electrical charge and very small magnetic moment, but possessing angular spin momentum and high penetrating power. If the n. exists, then, in β -particle disintegrations, the neutron changes into a proton within the radioactive nucleus, with the expulsion, not of an electron only, but of two particles, an electron and a n., produced at the moment of emission. This postulated type of interaction in the nucleus would explain certain anomalies; for example, that, in the disintegration of radium, the sum of the separated parts, calculated in terms of energy, is less than the total of the original atom, the difference being represented by the n.

Neutron, Symbol 1_0n . A particle consisting of a proton and an electron in close combination, having therefore no perceptible electrical charge. A n. may become a proton by losing an electron; and a proton may become a n. by losing a positron. The n. and proton may thus be regarded as the same heavy particle in two different quantum states. If the mass of the hydrogen atom is 1.0081, that of the n. is about 1.009 on the atomic scale, or 1.674×10^{-24} gm. The binding energy of the electron and proton which form the n. is about one or two million volts. N. are ejected from the nuclei of beryllium or boron when bombarded by α -particles; for beryllium as follows:



Variations in the value of Q may lead to various degrees of excitation of the resultant carbon nucleus, with the emission of γ -rays. The equation for boron is:



N. are also produced by the impact of high-energy deuterons or protons. Having no charge, the n. is not repelled by atomic nuclei as is the α -particle, and in lesser degree the proton. It is thus more effective in promoting atomic disintegration. Reactions brought about by bombardment with n. are of at least three types: (i)

Capture of the n., *e.g.*— ${}^{238}_{92}\text{U} + {}^1_0n \rightarrow {}^{239}_{92}\text{U} + \gamma$. The new element is an isotope of the old. (ii) Capture of the n. and emission of a proton, *e.g.*— ${}^{28}_{14}\text{Si} + {}^1_0n \rightarrow {}^{28}_{13}\text{Al} + {}^1_1\text{H} + Q \dots$, giving an element one place lower in the Periodic Table (q.v.). (iii) Capture of the n. and emission of an α -particle, *e.g.*— ${}^{14}_7\text{N} + {}^1_0n \rightarrow {}^{11}_5\text{B} + {}^4_2\text{He} + Q \dots$, the product being two places lower in the Table.

Since each nucleus is composed of neutrons and protons bound by strong but short-range forces, the energy of a captured n. must be distributed among all the particles which previously comprised the nucleus. In practice this energy may be distributed selectively, so as to cause the emission of a proton or an α -particle, or there may be time during the life of the compound nucleus for the excess energy to be emitted as radiation.

Ni-Carbing. A process which is a combination of carburizing and nitriding, applied to iron and steel parts by heating at temperatures between 1200° and 1600° F. (650° and 870° C.) in an atmosphere

Nib

containing both carburizing gases and ammonia. The final hardness, which is much the same as that of a cyanided case, is obtained by quenching in oil and water. The time cycle is very short (2-3 hrs.) as compared with the usual nitriding (50 hrs.), and a case of 0.006-0.008 in. thick is obtained.

Nib. In Powder Metallurgy, a pressed, pre-sintered, shaped, sintered, hot pressed, rough drilled, or finished compact. Also: A generic term used for a piece of hard carbide material intended for use as a drawing die (A.S.M. Defn.).

Nickel. Ni. El. A.W. 58.69; At. No. 28; S.G. 8.9; M. Pt. 1455° C. Greyish-white metal resembling iron; very malleable and ductile; a poor conductor of heat and electricity; magnetic; very resistant to corrosion. Occurs as *smaltite*, $(\text{NiCoFe})\text{As}_2$; *niccolite* or *kupfer-nickel*, NiAs ; *nickel glance*, NiAsS ; *millerite*, NiS ; *garnierite*, $(\text{NiMg})\text{H}_2\text{SiO}_4$; *pentlandite*, $(\text{NiCuFe})\text{S}$, and other minerals. Extracted, chiefly from pentlandite, by roasting, smelting with coke and bessemerizing, to produce a matte rich in copper and n. By roasting and reducing the oxides with carbon in open-hearth or electric furnaces, Monel metal, an alloy in considerable industrial use, is produced, containing 68 n., 28 copper and 4 per cent. of manganese and iron. To obtain metallic n. by the Mond process, the matte is roasted to oxide, which is then treated with carbon monoxide to produce n. carbonyl, $\text{Ni}(\text{CO})_4$, a gas which decomposes when heated to 180° C., so that the n. is deposited, and carbon monoxide liberated once more. The metal can thus be obtained as pellets of 99.8 per cent. purity, ready for the market. N. itself is used extensively for coinage, cooking utensils and electroplating. N.-copper alloys are used for coinage and heat- and corrosion-resisting purposes; n. silvers (n.-copper-zinc alloys) for decorative and electrical resistance purposes, etc.; n.-chromium and n.-chromium-iron alloys for high-temperature and electrical resistance purposes, and n.-iron alloys, which have high permeability and resistivity, for various electrical duties. N. is used extensively in various alloy steels, bronzes and other non-ferrous alloys.

Nickel Steels. N. forms solid solutions in all proportions with iron, giving rise to s. consisting, as the content of n. increases, of ferrite and pearlite, ferrite and martensite, martensite only, martensite and austenite, or austenite only, on slow cooling. An ordinary mild s., containing some 0.2-0.3 per cent. of carbon, to which some 3-3.5 per cent. of n. has been added, consists of a tough matrix, in which is set fine pearlite, to give a s. of increased strength without prejudice to ductility. Such s. have many structural applications (e.g., turbine pinion shafts, piston rods, etc.), while n.

case-hardening steels are also used. The A_{c1} change point, which varies with the carbon content, is lowered as the n. content increases (by about 10° for each 1 per cent. of n.), the A_{r1} point being also lowered, to a greater extent; and, on approaching 10 per cent. of n., is very greatly reduced, such s. being termed *irreversible* (q.v.). N.s. are commonly used in the hardened and tempered state, and can thus be hardened at temperatures lower than with the equivalent carbon s.; while a greater range of hardening temperature is permissible without undue grain growth, which is retarded by the slow diffusion of the n. With higher proportions of n. (15–25 per cent., or still lower with higher carbon contents) the alloys are martensitic on slow cooling; and, above 30 per cent., austenitic when so cooled. Austenitic n.s. are soft and tough, but, with a higher carbon content, become hard and brittle when cold-worked, owing to the production of martensite. Owing to their cost, the martensitic and austenitic n.s. are little used in constructional work, but the 36 per cent. n. alloy with low carbon content has an expansion coefficient of almost zero, and finds much application, under the name of *Invar*, in clocks, geodetic instruments, etc.

Nickel-Chromium (N.-Chrome) Steels. The presence in s. of n. to the extent of 4.5 per cent. (max.) and cr. to 1.25 per cent. (max.) (although lower proportions of both are usually employed) enables one to combine in great measure the advantages of both elements. Thus the grain-growth tendency of cr. is corrected by the n.; and the graphitizing tendency of n. by the cr. The hardenability is much increased, so that, when treated in large masses, a structure much more homogeneous than with carbon steels is obtained. With a higher proportion of n., 3.75 per cent. or so, the s. can be effectively hardened at lower rates of cooling, and a s. containing 4.5 per cent. n., 1.25 per cent. cr. and 0.35 per cent. carbon, becomes air-hardening (q.v.). N.-cr.s. are always used in the hardened and tempered state, and show a range of mechanical quality, variable over wide limits, characterized by a ductility higher for an equivalent strength than with carbon steels, and good fatigue resistance and wearing properties, being thus used extensively in automobile and aero work, for armour plate, etc. When slowly cooled, they may suffer from temper brittleness (q.v.), which, however, can be corrected as described. Much higher proportions both of n. and cr. are used in the austenitic stainless s. (q.v.) and in heat-resisting s. (q.v.).

Niobium. See Columbium.

Nital. An etching reagent consisting of an alcoholic solution of nitric acid (1 or 2 per cent.), employed: (1) for developing the ferrite grain boundaries of low-carbon steel; (2) where maximum contrast

Nit

between pearlite and cementite is required; and (3) for many alloy steels which are scarcely attacked by picral.

Nitr alloy Steel. See Nitriding.

Nitrarding. See Nitriding.

Nitration. See Nitriding.

Nitriding (Nitrogen-Hardening, Nitration or Nitrarding). A process for superficially hardening steel, in which the part, in a finish-machined state, is heated to a temperature of about 500°C . (say 950°F .) for some 40–90 hrs. in an atmosphere of ammonia gas, which dissociates, part of the atomic nitrogen so formed passing into solid solution as iron nitride, Fe_4N , in the outer layers of the steel. These are thus impregnated with nitrogen, to produce a case of intense hardness (900–1100 Brinell or 102–113 Shore) without the need of further heat treatment. N. cannot be applied successfully to ordinary carbon steels, where the surface hardness is increased only slightly by such treatment, and the case is very brittle. It is used only for particular classes of alloy steels, those chiefly employed, containing aluminium, chromium and molybdenum, being known collectively as “Nitr alloy steel”. The fact that quenching is unnecessary avoids the possibility of cracking and reduces distortion to a minimum. Parts which must be kept soft, as threads or key-ways, can be protected from the action of the gas by tinning.

Nitrogen-Hardening. See Nitriding.

Noble Metals. M., such as gold, platinum, etc., at the positive end of the Electrochemical Series (q.v.), and therefore not readily affected by atmospheric corrosion or acid attack. Cf. **Base M**.

Nodule. (1) A small rounded irregularly-shaped mass, as those of graphite in malleable cast iron (q.v.). (2) In Powder Metallurgy, the knotted, rounded, or other similar shapes observed in metal powder particles (A.S.M. Defn.).

Non-Corrodible. That which cannot be corroded. Sometimes improperly rendered as “non-corrosive”, which refers to the reagent, and not to the material resisting attack.

Non-Corrosive. Of a reagent which, under the particular conditions, does not give rise to attack of the material. Sometimes improperly used for *non-corrodible* (q.v.).

Non-Destructive Testing. Methods of examination, usually for soundness, which do not involve destroying or damaging the part being tested. It includes radiological examination, magnetic testing and so forth.

Non-Ferrous Alloy. An alloy composed substantially of elements other than iron ; in which, however, iron may be present either as an impurity, or in such a proportion as not to make it the preponderating element.

Normalizing (or Normalization). The heating of steel (usually hypo-eutectoid) to a temperature exceeding by some 50° C. its upper critical temperature (A_{c3}), followed by cooling freely in still air, so that moderately rapid cooling occurs and a fine-grained ferrite-pearlite structure is obtained. The efficacy of n. decreases with increasing section, when cooling is necessarily more prolonged, and in the interior of the mass the process may approximate to annealing. The objects of n. are : (1) the removal of strain-hardening effects due to finishing forging at too low a temperature ; (2) the substitution of a fine-grained structure for a coarse-grained one ; such as may result—either locally or generally—from overheating, finishing forging at too high a temperature, or too slow cooling ; (3) the production of a structure of mechanical quality as uniform as possible ; and (4) the improvement of machinability, as compared with that of a slowly-cooled steel. The n. of a steel previously cooled slowly leads usually to a definite increase in the yield point, ultimate stress and hardness values, with some reduction in ductility.

Notch Brittleness. Brittleness, or undue liability to fracture, as shown by a notched-bar test. Notched-bar values are frequently termed "impact" values, because they are usually determined by an Izod, Charpy or similar test, in which shock is a factor. Shock, however, is not an essential factor in notched-bar testing, because Izod values obtained, as in the Tensometer Testing Machine, by slow bending applied on the side of the test piece opposite to the notch, generally agree very well with those obtained in the usual machine, in which test shock is a factor. *See also Impact Testing, Notch Sensitivity, etc.*

Notch Effect. The effect of localized concentration of stress caused by notches, sharp corners, re-entrant angles, scratches, tool-marks, oil grooves, or other surface discontinuities. These always cause a local peak stress predisposing to failure, as the cracking of high-carbon steel tools when quenched, and the fatigue failures of working parts. Both of these types of failure frequently originate in such stress-raisers (q.v.).

Not

Notch Sensitivity (or Sensitiveness). The extent to which a material is incapable of retaining its ductility when notched; the extent to which it is unable to yield locally, so as to reduce high local stresses, as those arising from notches and other stress-raisers (q.v.). The amount of ductility necessary to avoid failure depends upon the amount of plastic flow required to reduce the peak stress sufficiently. For different steels, n.s. varies greatly. In general, the higher the tensile strength and the lower the ductility, the greater the n.s. As the degree of cold working increases, so also does the n.s. As damping capacity increases, n.s. is reduced. N.s. should be distinguished from "velocity-sensitivity", revealed by impact testing, a measure of the capacity to deform suddenly and rapidly before failure.

Nuclear Charge. *See* Atomic Number.

Nuclear Mass. *See* Atomic Weights.

Nuclear Mass Number. *See* Atomic Weights.

Nucleation. The process by which recrystallization starts from a series of centres. Thus, crystals of γ -iron develop chiefly from centres situated at the boundaries of the ferrite grains, where particles of cementite or pearlite serve to initiate the transformation. The finer the ferrite grain size, the finer the austenite structure developed from it. N. can be studied by quenching, so as to arrest the process at various stages. *See also* Inoculation, Metastable Equilibrium, etc.

Nucleus. (1) In the crystallization of a metal or alloy, one of the small solid particles first separating at different points in the liquid mass, from which nuclei crystallization proceeds at a large number of different centres, to form an aggregate (q.v.). (2) The positively-charged "core", or central mass, of the atom (q.v.).

O

Occlusion. The absorption or condensation of a gas, usually of hydrogen, within the pores of a metal, notably of palladium and platinum. *Cf.* Adsorption.

Oil Flow, Rate of. In Powder Metallurgy, the rate at which oil will pass through a sintered porous compact under specified test conditions (A.S.M. Defn.).

Open-Hearth Process (Siemens or Siemens-Martin P.). A p. for making steel by refining a mixture of pig iron and steel scrap (which takes less time than refining an all-pig charge) melted in the shallow hearth of a regenerative furnace, fired with producer or other gas and liquid fuel. The furnace lining is appropriate to the p., either acid or basic (q.v.). Carbon, silicon and manganese are removed by reaction with an oxidizing slag, whose composition is adjusted by the addition of hematite iron ore in the acid, or of hammer scale (Fe_3O_4) in the basic p. By taking a small sample from the bath and conducting a rapid analysis, the state of the melt is determined at intervals. The contents of carbon and manganese may be too much reduced in refining, while the melt also requires deoxidation. Deoxidation and recarburization are accomplished by the final addition of spiegel or ferro-manganese containing the requisite amount of carbon; while other deoxidizers, as ferro-silicon and aluminium, are also used. After a suitable interval for the separation of impurities, the steel is tapped. Sulphur and phosphorus are not removed in the acid p., and the charge must be suitably low in these impurities. Acid O.H. capacity may be some 90 tons, 40 tons being a usual size, and the process may take from 10 to 16 hrs. In the basic O.H.p., phosphorus is also removed, by reaction with the basic slag. Too high a silicon content in the charge leads to waste of lime, and delays the p. Manganese is not removed very rapidly and the content should not be too high. Deoxidation of a basic melt cannot be carried out in the presence of the slag, or the phosphorus will be returned to the metal. The p. is thus usually effected in the ladle after tapping, the slag being kept out. The period for removal of deoxidation products is thus limited to that avoiding undue cooling. Basic O.H. capacity may be as great as 400 tons, an "average" size being 150 tons. The basic p. takes somewhat longer than the acid p. *See also* Acid Steel, Basic Steel, Deoxidizers, Killed Steel, Rimming Steel, etc.

Ora

Orange-Peel Effect. A defect shown by brass sheet which has been annealed at temperatures above $750^{\circ}\text{C}.$, causing "over-annealing", attended by a coarsely crystalline structure, when the outlines of the individual grains are seen on the surface after subsequent cold working, as in a deep pressing, giving a rumpled surface, which is thus described.

Orbit. Path conjectured to be followed by electrons round the nucleus.

Order-Disorder Transformation. See Solid Solution.

Ordinary Iron. A term sometimes applied to the usual grey cast i., to distinguish it from malleable cast i., high-duty cast i., or alloy cast i.

Ordinary Steel. Carbon s. (q.v.).

Orientation. The directions in space of the axes of a crystal grain. Metals and solid solutions usually crystallize in one of the three following systems: (1) Cubic, Isometric or Regular; (2) Tetragonal; (3) Hexagonal (q.v.). In a cast homogeneous polycrystalline aggregate, orientation is constant in any one grain, but usually varies quite irregularly (random o.) from one grain to another throughout the mass, because solidification has started more or less simultaneously from a large number of different nuclei. In metals and alloys cold-worked and annealed, there is often a tendency for the grains to assume a similar or preferred o. (q.v.). Fringe crystals (q.v.) also show similar o.

Osmium. Os. El. A.W. 191.50; At. No. 76; S.G. 22.48; M. Pt. $2500^{\circ}\text{C}.$ Hard lustrous bluish-white metal, the heaviest known, unaffected by air at ordinary temperatures, very resistant to corrosion; very difficult to work, but the powder can be sintered at a temperature below $2000^{\circ}\text{C}.$, and o. is now available clad on one of the heavy base metals (nickel, brass, copper or steel) in the form of sheet, rod, wire and tube. Occurs as *osmiridium*, a natural alloy of o. and iridium, with small amounts of other metals. Extracted by a complex wet process. Used as a catalyst, particularly in hydrogenations; and as an alloy for tipping fountain-pen nibs. Formerly used for filaments of electric bulbs.

Osmosis. The passage of liquids and dissolved substances through a membrane. The solution pressure giving rise to this passage is known as *osmotic pressure*. See Colloid, Dialysis, etc.

Over-Drawing. See Hollow-Drawing.

Overheating. The heating of a metal or alloy to a temperature such as will produce a structure of undesirably coarse grain, but not cause permanent damage. The development of a coarse grain is often facilitated by previous cold work, as with 70 : 30 brass. With mild steel, heating at a sufficient temperature above the A_{c_3} point gives rise to coarse austenite; and, after cooling, to a coarse ferrite-pearlite structure of inferior quality. O. does not refer to the temperature range just short of incipient fusion, steel heated in this region being described as "burnt" (q.v.); while a similar effect is found in brass. Overheated structures can be refined by subsequent heat treatment (*e.g.*, normalizing of steel), by mechanical work, or by a combination of the two (*e.g.*, over-annealed brass can be cold-worked, re-annealed and thus refined). Overheated steel, however, may be superficially decarburized, and the prejudicial effect of this is lasting. See also Grain Refinement, Normalizing, Recrystallization, etc.

Overpoled. See Poling.

Overpotential or Overvoltage. The liberation of hydrogen gas from acids of ordinary concentration is postulated as occurring only with the metals later than hydrogen in the Electrochemical Series (q.v.). On a blackened (rough) platinum surface, hydrogen gas is thus evolved as soon as the potential becomes slightly more negative than the normal electrode potential. But on any other metal, whose surface may play an important part in the reaction, the potential must be depressed still further before gaseous hydrogen is evolved. The difference between the normal electrode potential and the more negative value required on any other metal before gaseous hydrogen is liberated is termed the o.

Overstress. Stress exceeding the initial elastic limit.

Overwork. Excessive mechanical deformation in the cold, causing increased strength and hardness, with a corresponding reduction in ductility, and leading in extreme cases to the hollow drawing of bars, the exfoliation of sheets, or the cracking of parts made of thin sheet. It is avoided by suitably restricting the amount of cold work performed at each stage in the process; and by adequate annealing after each stage.

Oxide films. The thin layers of metallic o. produced on metals and alloys by the action of oxygen or oxidizing reagents, either at elevated temperatures, as with the temper colours of steels, or the

Oxi

“ skin ” on the surfaces of molten metals ; or at ordinary temperatures, as when superficial chemical attack leads to the production of a passive f. on iron, protecting the underlying metal from attack. Stainless steel is an example. In oxidizing media, such f. are self-healing. Protective o.f. are also produced artificially, as in the anodizing of aluminium and its alloys. O.f. on solid metals are usually crystalline, but the protective f. on aluminium alloys are amorphous.

P

Pack. A number of sheets of steel or other material piled together, with the longer ones at the bottom, for rolling down into a lighter gauge.

Pack-Annealing. The annealing of sheets which have been stacked on the flat in a pack or pile about 2 ft. high, either on a bogey or in a pan, and covered with a cast- or wrought-iron box cover, with sand at the sides to exclude air and minimize oxidation. After annealing for several hours at a low red heat, the sheets are allowed to cool slowly, being then known as "close-annealed sheets".

Pack-Carburizing. The carburizing of parts packed in boxes or other containers, an adaptation of the older Cementation Process. *See Carburizing and Cementation.*

Pack-Hardening. The usual case-hardening process (q.v.). *See also P.-Carburizing.*

Pack-Rolling. The r. of a number of sheets together, in a "pack". Sticking of the sheets (*e.g.*, steel sheets for tin-plate) is avoided by the use of a suitable steel, *e.g.*, one containing enough phosphorus; which, however, is undesirable when present in excess of 0.1 per cent. Less phosphorus is necessary with steel deoxidized by the addition of silicon or aluminium (killed or semi-killed).

Packing Material. In Powder Metallurgy, any material in which compacts are embedded during the pre-sintering or sintering operation (A.S.M. Defn.).

Palladium. Pd. El. A.W. 106.70; At. No. 46; S.G. 11.9; M. Pt. 1555° C. Lustrous white metal, very malleable and ductile, very resistant to atmospheric attack and corrosion attack in general; occludes hydrogen to the extent of 800 times its own volume at room temperature. Occurs alloyed with platinum. Extracted by a complex wet process. Used, as p. leaf, as a decorative and protective coating on wood, ceramics, leather and metal; base metal clad with p. is used as sheet and tube for chemical equipment for the preparation of pure products; and the metal is also used in telephone relay contacts, and for jewellery, where it replaces platinum. Alloys of p. with rhodium and ruthenium are also used for jewellery. A 50 : 50 p.-silver alloy is used as a dental

Pan

casting alloy, and an alloy containing up to 30 per cent. of p., with gold, silver and copper, is used for the same purpose.

Panelling. See *Stretcher Strains*.

Parallel Growth. A homogeneous aggregate (q.v.) in which the crystals are uniformly oriented, so that the corresponding axes of all crystals are p.

Parkerizing. A rust-proofing process for iron and steel parts. These are descaled and degreased, preparatory to a bath treatment for some 40–90 mins. at a temperature of 208° – 210° F., to coat the surfaces with a layer composed substantially of insoluble manganese phosphate, with some ferric phosphate. The part is then rinsed in water at 180° F., and finished by staining and oiling; or by painting. In a further development (P.D. process), the coating is composed almost entirely of zinc phosphate, with very little ferric phosphate. Processing takes about 35 mins. at 175° – 185° F. (max.), while the working costs are somewhat lower.

Particle Size. In Powder Metallurgy, the controlling lineal dimension of an individual particle as determined by analysis with screens or other suitable instruments. *Particle Size Distribution.*—The percentages expressed in terms of weight of the various sizes of particles in a powder sample when classified in terms of size ranges, and measured in terms of screen mesh or microns (A.S.M. Defn.).

Pass. (1) In welding, the metal deposited by fusion during one passage of the filler metal along the joint; also known as a run. (2) In rolling, each passage of the piece of steel, or other metal, from one side of the rolls to the other. A *live* p. is one in which the steel is mechanically worked during the operation; a *dead* p. is one in which no alteration in cross-section is effected, as in the case of the return of the material over the top roll of a pull-over mill for re-entry. Instead of *pass*, the term, *gate*, is sometimes used. (3) In rolling, the actual gate.

Passivity. A surface condition of metals and alloys, such as may result from the prior production of a resistant oxide film of sensible thickness, whereby the material is not attacked by a reagent which would normally affect it. Thus, iron which has been rendered passive by immersion in strong nitric acid can then be safely immersed in acid of lower concentration, such as would rapidly attack iron which had not previously been made passive. P. may be induced by the presence of films other than oxide films.

Patenting. A high-temperature normalizing treatment applied to steel rod and wire, previous to further drawing, in order to produce a sorbitic structure and facilitate the working process. The rod or wire, containing usually 0.55–0.85 per cent. of carbon, is passed through open tubes in a furnace at about 970° – 1000° C., emerging after a short distance into the air, where it either cools freely or is passed through a bath of molten lead or salt at about 550° C. This treatment results in the production of material having a sorbitic structure, and also, by virtue of the high normalizing temperature, a coarse grain. In this state, however, drawing is most readily accomplished, a reduction of area of some 90 per cent. being possible; while a tensile strength of 100–120 tons per sq. in. can readily be obtained.

Patina. An oxidation film produced on bronzes either by previous chemical treatment of the surface; or by prolonged exposure to atmospheric attack.

Pauli's Exclusion Principle states that no two electrons in an atom can have at the same time identical values of the four quantum numbers, n , l , m and s . The possible states of an atom having a given number of electrons are thus restricted, a circumstance which has an important bearing on the relation of atomic structure to the Periodic Table (q.v.). See also **Electronic Structure**.

Pearlite. The lamellar eutectoid aggregate of ferrite and cementite in steel, resulting from the transformation at A_{r1} (about 690° C.), when the residual austenite, which, by the gradual rejection of ferrite (or cementite) has attained the composition of the eutectoid, *i.e.*, about 0.85 per cent. of carbon, is transformed into p. Cementite is much harder than ferrite, and, after polishing, is left in relief, so that, when etched and illuminated obliquely by white light, as for micro-examination, it acts in much the same way as a diffraction grating, giving rise to the iridescent colours seen in mother-of-pearl, where the effect is produced in a similar manner, the eutectoid having been named p. for this reason. The term should therefore be strictly reserved for structures, however fine, consisting of thin plates or lamellæ, which give rise to the effect described, and the tendency to describe as p. all eutectoid structures, whether the dispersed phase is lamellar or granular, should be discouraged. P. contains about 12.74 per cent. of cementite and 87.26 per cent. of ferrite, and is produced in the cooling of steel through the critical temperature range at a rate slower than the critical cooling rate (q.v.). With varying rates of cooling, it may occur at temperatures which are depressed to a greater degree as the rate of cooling is greater. The higher the temperature at which p. is formed, the

Pea

greater the coarseness and the lower the Brinell hardness. This varies greatly with the fineness of structure, approximately as follows: Coarse, 210; Medium, 315; Fine, 420.

Pearlitic Malleable Cast Iron. The product obtained by a heat treatment of white cast iron which converts some of the combined carbon into graphite but which leaves a significant amount of combined carbon in the product. (A.S.T.M. Tent. Std. Defn., A196—42T.)

Peltier Effect. A difference of potential set up at the junction of two dissimilar metals. With a copper-iron junction which is the hot junction of a thermoelectric circuit, if current (which may be generated externally) flows from the copper to the iron across the hot junction, this junction tends to be cooled, showing that energy is absorbed, and the current is flowing up a potential slope. But the cold junction, where the current is flowing from the iron to the copper, tends to be heated, showing that energy is being liberated, and the current is flowing down a potential slope (iron being positive to copper at ordinary temperatures). This cooling of the hot, and heating of the cold junction, is the P.E., from which one can deduce the existence of a potential difference between two dissimilar materials in contact. In the determination of the electrical conductivity of a heterogeneous aggregate, a back E.M.F. is thus produced by the heating of the junctions of dissimilar constituents. The P.E. may lead, therefore, to the finding of a conductivity lower than that calculated from those of the constituents and the volume concentration. *Cf. Seebeck and Thomson Effects.*

Permanent Mould Casting. *See Die Casting.*

Pepper Blister. *See Blister.*

Periodic Law. The properties of the elements are a periodic function of their atomic weights (Mendeléeff, 1869). This is most clearly demonstrated when the elements are arranged in a Periodic Table (q.v.).

Periodic Table, System or Classification. As originally devised by Mendeléeff, an arrangement of the elements in order of ascending atomic weights, so as to demonstrate the p. repetition of properties by successive rows of elements. Mendeléeff was thereby enabled to predict the positions and properties of some then unknown but subsequently discovered elements, such as gallium, scandium and germanium; and to show that some accepted atomic weights could not be reconciled with their apparent positions in the P.T., and were

Per

therefore incorrect ; as, indeed, was found. But the P.T. still showed a number of anomalies that could not be accounted for, and it was revised by Moseley (1913-14), who replaced atomic weights by atomic numbers. An arrangement of the P.T. in its new form is shown.

It will be seen that elements with similar properties appear in regular positions and fall into a series of nine vertical *groups*, which are determined by a suitable arrangement, into short and long *periods*, of a continuous series of the elements in ascending order of atomic number. After hydrogen and helium, there are two short periods of 8 elements and two long periods of 18 elements, each of the last including three "transitional" elements with closely allied properties (Group VIII). Next comes a very long period of 32 elements (caesium to radon), including a transitional group of three elements, and also the 15 "rare earth" metals (at. nos. 57-71). All of these must be put into one place in the P.T., in the same group as the previous rare earth metals, scandium and yttrium, which they closely resemble. The periodicity of the later elements of higher atomic number is then maintained. The seventh period may represent the beginning of a second very long period. The long periods are divided into elements of even or odd atomic number, the "even" elements resembling in properties the "even" elements of the succeeding long period ; as also with the "odd" elements. Group I thus covers the alkali metals, lithium, sodium, potassium, rubidium and caesium, all of odd atomic numbers, chemically very similar, and showing, in the order given, in addition to a gradually increasing order of electropositiveness, an increasing complexity of electron configuration, an increasing atomic volume, and decreasing melting and boiling points. The other groups show similar relationships.

Peritectic Transformation. In the heating or cooling of an alloy, a transformation, occurring at a constant temperature, in which two phases react to form a new single phase. It is seen, for example, with steels containing between 0.07 and 0.7 per cent. of carbon, in which solidification is completed at 1494° C. by a reaction between the δ and liquid phases, to give rise to a single phase, γ . Alloys in which the two phases are present in a certain ratio consist after the reaction entirely of the new phase ; those containing an excess of one of the two original phases still showing some of this phase. With ordinary rates of cooling, p.t. are always incomplete.

Perlit Iron. See Lenz P.I.

Permanent Set. See Plastic Strain.

Phase. A completely homogeneous, mechanically separable and spatially distinct portion of a heterogeneous system, such as an element, compound or solution, or any state of a single substance, solid, liquid or gaseous. A system of three phases is seen in the case of a mixture of ice, water and water vapour existing in a previously evacuated and closed container. A eutectic alloy consists of two phases, for the constituents are spatially distinct and of different chemical composition. A phase may be *continuous*, as the major constituent—usually a solid solution—of a duplex or more complex alloy; or may be distributed as lamellar or granular particles through the continuous phase, when it is said to be *dispersed*. This p. is frequently the harder, when, the greater the dispersion, varying with heat treatment, the greater is the strength and hardness, and the less the ductility of the alloy. In the normal mild steels, ferrite is the continuous and cementite the dispersed p.

Phase Field. The area in a constitutional or equilibrium diagram occupied by a single phase or a mixture of two phases. A field in which two phases are present usually separates two single-phase fields occupied by each of these separate phases, respectively.

Phase Rule (Gibbs) “ defines the state of a system in equilibrium entirely by the relation existing between the number of components and the number of phases present, quite independently of the amount of each phase, and of the molecular constitution of the participating substances ”. It is generally stated as follows:

$$F = C + 2 - P$$

where F is the number of degrees of freedom, C is the number of components and P the number of p. of the system. In the case of metals and alloys, the pressure is usually constant, so that this factor can now be neglected, and the formula becomes:

$$F = C + 1 - P.$$

Thus, for pure metals, the number of components is 1 and the maximum number of p. (since F cannot be negative) is 2. Since $F = 0$, these two p. can exist only at one definite temperature, that of the melting point. Similarly, when an allotropic modification occurs in a pure metal, the two modifications can co-exist in equilibrium only at one definite temperature. In a binary alloy, the number of components is 2, the two pure metals. The formula can now be expressed:

$$F = 3 - P.$$

If only one p. is present, when the alloy consists either of a homogeneous liquid or solid, the number of degrees of freedom are two, i.e., it is possible to vary both temperature and concentration

Pho

independently. It also follows that 3 p. can exist simultaneously in equilibrium, but, since $F = 0$, only at one definite temperature. Where there are 2 p. in equilibrium ($F = 1$), the temperature is an independent variable. It should be noted that the P.R. applies strictly only to alloys which are in complete equilibrium, and many industrial alloys are not, when redundant p. may be shown, but disappear when true equilibrium is obtained.

Phosphor Bronzes. Tin-copper alloys containing definite proportions of phosphorus, and falling very approximately into three classes: (1) The "malleable" p. br., containing 3-7 per cent. tin, 97-93 per cent. copper, and a maximum of 0.20 per cent. of phosphorus. These alloys are soft, ductile and malleable; and are generally used in a forged or rolled state for pump spindles, turbine blades, boiler fittings and similar purposes, for which the chief requirements are strength and ductility. Here p. br. show mechanical quality comparable with that of mild steel and are much superior to steel in corrosion-resistance. (2) The "cast" p. br., containing 8-14.5 per cent. tin, 91.5-85 per cent. copper, and 0.25-1.5 per cent. phosphorus. Lead may sometimes be added, when a proportion of nickel is advantageous, hindering segregation of the lead. These alloys are very hard and brittle, having very low ductility, and are used for bearings, gearwheels and similar parts, where the chief requirements are hardness and wear-resistance, and ductility is of secondary importance. (3) B. in which phosphorus is used merely as a deoxidizer, little or none remaining in the final alloy, are also described as p. br. Here the properties are those of the bronze (q.v.).

Phosphorescence. The radiation at low temperature from a body, of light resulting from the absorption of radiant energy (as heat or light). P. differs from fluorescence (q.v.), in that the substance glows *after* the supply of incident radiant energy is cut off. P. is shown by the sulphides of the alkaline earths containing minute amounts of salts of the heavy metals, as Bi, Sb, Cu, Mn or Pb.

Phosphorus. P. El. A.W. 31.02; At. No. 15. Non-metal. Five allotropes. Its metallurgical interest is as an impurity or an addition in the following: (1) In steels, it is an undesirable impurity, existing as the fusible iron phosphide, Fe_3P , dissolved in the ferrite, and segregating to a considerable extent during solidification, so that the portions of the ingot last to solidify, viz., the axis and upper portion, show much higher proportions. On rolling, the high-p. ferrite regions are elongated into bands, alternating with those of pearlite, and known as *ghost lines* or *ghosts*. P. progressively reduces toughness (shock resistance) and more than 0.06 per cent. should not

be permitted. Up to 0.15 per cent. has been used in free-cutting steels of poor quality. (2) In cast iron, p. occurs as iron phosphide, a constituent of the $\text{Fe}_3\text{C} : \text{Fe}_3\text{P}$ eutectic, which solidifies at $950^\circ \text{C}.$, and persists in white irons down to normal temperatures. In grey irons, the silicon causes the carbide to break down to iron and graphite, leaving the phosphide structurally free. This constituent frequently occurs as a network round the pearlite grain boundaries. P. has no effect on the condition of the carbon, but reduces the solubility of the iron for carbon, thus acting indirectly as a hardener, particularly against abrasive wear. As the phosphide eutectic has the lowest melting point of any constituent, p. promotes fluidity. High-p. castings are, however, very weak and brittle. Maximum strength for irons of various compositions is associated with a range of 0.040 per cent. of p., and 0.60 per cent. is a safe limit for good-quality castings. (3) In phosphor bronze (q.v.).

Phosphorus Banding. *See* Ghost.

Photoelasticity. A photographic method of showing the distribution and magnitude of the stresses produced in structural and machine parts under load. The method depends upon the examination of stressed celluloid models, examined by polarized light.

Photomicrograph (often contracted to *Micrograph*, q.v.). A photographic reproduction of a microscopic object on a magnified scale. It should be noted that a *microphotograph* is a photograph reduced to microscopic size.

Physical Properties. Those properties of a material which do not involve any change in its chemical composition.

Pickling. The immersion of steel in dilute hydrochloric or sulphuric acid, to dissolve surface scale (q.v.), and/or to reveal flaws, etc. A small quantity of an organic restrainer, such as glue or starch, is added to reduce the acid attack on the exposed metal. P. is commonly applied before cold working, to ensure accuracy of dimensions and good finish; and is essential in the manufacture of drop-forgings, revealing laps and other defects which may not be shown when the work is cleaned by tumbling or sand-blasting. Hydrogen evolved in the process is absorbed by the steel, causing embrittlement, as shown if further cold working is attempted too soon after p. Ageing for 24 hrs., or heating at $200^\circ \text{C}.$, corrects this brittleness. P. may also be applied to other alloys. For p. iron castings, hydrofluoric acid, or a mixture of this and sulphuric acid, is sometimes employed, the purpose of the hydrofluoric acid being to

Pic

dissolve any sand fused on to the skin of the casting, or to loosen any sand cores which may not have been completely removed in fettling.

Picral. An alcoholic solution of picric acid (*e.g.*, 4 per cent., or saturated solution, in 95 per cent. ethyl alcohol) commonly used for the etching of steel; and superior to nital (q.v.) in developing the structure of the finest pearlite in plain carbon steels. For certain alloy steels, a solution containing equal amounts of p. and of nital (1-2 per cent.) is more suitable. The addition, to a 1 per cent. picral solution, of 5 per cent. of hydrochloric acid, provides a reagent capable of revealing, in martensitic steels, the outlines of the prior austenite grains.

Piercing. The process of producing a hole in metal by forcing through it a pointed tool, the metal so displaced forming part of the wall of the article. P. is commonly used for making steel tubes from solid steel bars. *Cf.* **Punching.**

Pig Iron. The product of the reduction of iron ore (which consists essentially of iron oxide, Fe_2O_3 or Fe_3O_4 , with silica and other impurities) by means of coke at a high temperature in a blast furnace. A flux of limestone is used to remove the siliceous impurities. The resultant p.i., which is tapped out at the bottom—and either run into pigs, or held in a molten condition for charging into a steel-making furnace—contains some 3.5-4.0 per cent. of carbon, with silicon, sulphur, phosphorus and manganese, which have been reduced with the iron. *See also* **Cast Iron.**

Figs. The iron cast in the lateral channels branching off from the main sand channel, into which the stream of molten iron from the blast furnace is run. Iron cast in chill moulds, so as to obtain a product free from sand, is known as machine-cast p.

Pill Press. In Powder Metallurgy, a pharmaceutical pill press adapted to form compacts (A.S.M. Defn.).

Pine-Tree Crystal. *See* **Dendrite.**

Pinhead Blister. *See* **Blister.**

Pinholes. Minute gas holes in cast metal, particularly in the heavier sections of sand-cast aluminium alloys, the lighter sections, and die-castings as a whole, rarely showing them. P. are due, usually, to the presence, in the furnace atmosphere, of water vapour. This is reduced by the molten metal, some of the hydrogen thus formed passing into solution in the melt, the aluminium oxide

remaining mechanically entangled in the same. P. arise from the liberation of this hydrogen on solidification. They are revealed, usually, only on machining. Being discontinuous, p. do not really constitute *porosity*, although the term is sometimes applied to this defect. P. are avoided either by melting without gas contamination; or by bubbling through the molten metal an equal mixture of chlorine and nitrogen gases at a temperature not exceeding 700°C . With some alloys, as Y-alloy, the use of a proportion of titanium tetrachloride is advantageous; as also the use of patent fluxes, such as the 2 : 1 sodium chloride : sodium fluoride mixture.

Piobert Effect. See *Stretcher Strains*.

Pipe. A hollow cavity situated at the top and towards the axis of a cast ingot or other massive casting, and due to shrinkage in volume during solidification, with insufficient feeding down of further liquid metal to compensate for this shrinkage. Its extent is greater, the higher the temperature at which the metal is poured. Its effects are minimized by the provision, on the ingot or casting, of an adequate feeding head, which is then discarded. Alternatively, the top portion of the ingot is cropped to the extent of 25 per cent., or so, this portion being rejected. Piping is particularly pronounced in killed steel ingots, but may be almost entirely absent in those of rimming steel.

Piping. The production, during the solidification of an ingot or other massive casting, of a pipe or pipes (q.v.).

Pit. A local depression in a metallic surface caused by corrosion-attack over a minute area. Such attack is promoted by the existence of a small surface cavity, to the bottom of which atmospheric oxygen cannot readily gain access, so that this region becomes anodic to the surrounding metal and is selectively attacked.

Planck's Constant. According to Planck's Theory, radiant energy is to be found only in units whose energy is proportional to the frequency of atomic vibration characteristic of the particular solid. Thus the value of the unit, or quantum, $\epsilon = h\nu$, where h is P.C. and ν the frequency. P.C. is thus the factor by which the frequency must be multiplied to give the quantity of energy in ergs contained in a quantum. The value of P.C. is approximately $6.61 - 6.63 \times 10^{-27}$ erg-secs. The value of a quantum must thus vary with the particular element.

Plastic Flow. The deformation of a metal by movement along the slip planes and at the grain boundaries, the effects varying

Pla

according to the temperature at which the process is performed.
See also Slip Bands, Creep, etc.

Plastic Strain (Permanent Set or Permanent Deformation). Strain which persists when the stress giving rise to it has been removed.

Plasticity. That property of a body by virtue of which it tends to retain its deformation after reduction of the deforming stress to its yield stress. (A.S.T.M. Std. Defn., E24—42.)

Plasticity, Crackless. *See Crackless Plasticity.*

Plate. (1) A flat piece of steel or other metal obtained by rolling (q.v.), and usually over $\frac{1}{8}$ in. in thickness. In some classifications, however, sheet includes the $\frac{3}{16}$ in. thickness, p. starting at $\frac{1}{4}$ in. (2) In Powder Metallurgy, *plates* are flat particles of metal powder having appreciable thickness (A.S.M. Defn.).

Plated Bars. Bars or lengths of blister steel (q.v.) subjected to a preliminary hammering at an orange heat, in order to flatten out the blisters, and to make the brittle blister steel tough enough to withstand the severe work of welding in the manufacture of shear steel.

Plating. *See Electroplating.*

Platinum. Pt. El. A.W. 195.23; At. No. 78; S.G. 21.45; M. Pt. 1773.5° C. Greyish-white metal, lustrous when polished; a poor conductor of heat and electricity; highly resistant to corrosion. Occurs native, usually alloyed with a number of other metals. Extracted by a complex wet process, chiefly from Canadian nickel ores as a by-product of the Mond nickel process. Used as a catalyst in the manufacture of nitric acid, sulphuric acid and a number of organic products; for the manufacture of heat- and acid-resisting laboratory apparatus and chemical equipment, where p.-clad plant is being increasingly used; for jewellery, dies for producing glass rods to definite dimensions, etc. Alloys with iridium and rhodium are used as thermocouple elements, resistance furnace windings, contacts for low currents, fuse wires in detonating caps, etc. Alloys of the p. metals have replaced gold to a considerable extent in dentistry, where the alloys can often be manipulated in the soft state and given a hardening treatment when in final form.

"Poisoning." (1) Of a catalytic agent, the presence of a small proportion of an impurity which may prevent the catalytic agent from performing its function. Thus a small quantity of carbon

disulphide will prevent platinum black from exercising its power as a catalyst of hydrogenation. (2) The term is occasionally used, for metals and alloys in general, to describe the serious deterioration in mechanical quality which may result from contamination with a small quantity of impurity, as of bismuth in copper.

Poisson's Ratio. The ratio, within the elastic limit of the material, of transverse contraction to longitudinal extension, per unit length. It is of the order of 0.30 for steels.

Polar (or Ionic) Compound. A c. composed, instead of neutral atoms, of oppositely-charged ions, held together by electrostatic forces. The total of the outer electrons in a p.c. is either 8, or a multiple of 8. Sodium chloride is an example. The sodium atom has a single valency electron, while the chlorine atom has 7 valency electrons; in each case, outside a stable group of 8 electrons. The two atoms unite by reason of the sodium atom giving up its one valency electron to the chlorine atom, which now has a stable outer group of 8 electrons. A non-polar c. is one which is not ionized and where the total of the outer electrons is not 8; nor a multiple of it.

Poling. In the refining of blister copper in a reverberatory furnace, to produce tough-pitch copper, a process of stirring the molten metal with long green hardwood poles, balanced on a chain, in order to remove excess oxygen and other impurities from the metal. The reducing action is also promoted by short poles and charcoal placed on the surface of the bath. Tough-pitch copper is not completely deoxidized, but contains sufficient oxygen, between 0.03 and 0.10 per cent., to ensure the best mechanical quality, when it is soft and ductile, showing a silky fracture. If the p. operation is insufficient, the metal still contains too much cuprous oxide, making it brittle and unworkable, and is said to be *underpoled*. If the p. operation is continued too long, oxides of bismuth, antimony, etc., are reduced, and these metals alloy with the copper, making it brittle once more. Such metal is said to be *overpoled*.

Polish Attack. A method of developing the microstructure of a metal by a combined etching and relief-polishing attack, obtained by impregnating the cloth or other polishing material with a suitable amount of the etchant; and then polishing the specimen on it, preferably by hand. The relief effect is the greater, the more elastic the support.

Polishing. The last stage in the preparation of a metallographic specimen, prior to etching. Usually performed on a revolving disc, covered with a suitable soft cloth, which is wetted and impregnated

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with p. powder, usually alumina or magnesia. The operation differs from grinding in producing a minimum deformation, both superficially and in depth. P. should result in the removal of existing scratches from the last grade of emery paper used (OO or OOO), and the causation of no additional ones. When etching reveals once more the presence of scratches which had apparently been removed in p., this is due to the solution of the smeared metallic surface layer, produced in p., which has temporarily filled in the grooves. A similar effect is obtained in the smearing of a soft constituent over a hard one. Alternate light p. and etching will gradually remove all such scratches and surface effects, when etching will reveal the normal structure. When the metal or alloy contains inclusions, as those of graphite in cast iron, the thinner the p. cloth, the better. More important than the cloth is the degree of wetness, which should be at a minimum with cast iron. The best method for bringing out the structure of the inclusions is that of repeated light p. and etching.

Polycrystalline. Composed of many crystals. An aggregate, as distinct from a single crystal.

Polymorphism. An effect, akin to that of allotropy, by which metals or intermetallic compounds which are chemically similar differ in crystal form, changing from one form to another at a definite temperature. Those existing in two varieties are known as dimorphous, and those with three varieties as trimorphous.

Pore. In Powder Metallurgy, a minute cavity in a compact, formed either intentionally or unintentionally (A.S.M. Defn.).

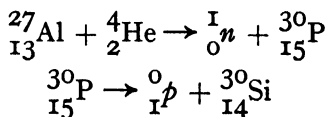
Pore-Forming Material. In Powder Metallurgy, a substance included in a powder mixture which volatilizes during sintering and thereby produces a desired kind of porosity in the finished compact (A.S.M. Defn.).

Porosity (or Sponginess). (1) The occurrence of interconnected cavities in a casting, such as will lead to its failure to withstand the stipulated hydraulic test. The presence of isolated blowholes or gasholes does not constitute p. as generally understood, although the term is sometimes applied to this effect. P. may be major or minor, the first being readily visible to the eye on cutting up the casting, and usually due to the presence of shrinkage cavities; while the second is not so readily discoverable, and may be caused by incipient shrinkage (q.v.) or other effects. (2) In Powder Metallurgy, the total volume of voids—generally distributed uniformly between the metal particles of the powder compact—and usually expressed as

a percentage of the total volume of the part. Intercommunicating P. is that type of p. in a sintered compact in which the pores are intentionally connected, so that a fluid may pass from one to another, or completely through. This quality would be better expressed by the term "permeability".

Porous Bronze. B., usually of the 90 per cent. copper : 10 per cent. tin type, produced by the sintering of mixtures of copper and tin powders, so as to produce a bearing material containing voids, varying between 25 and 40 per cent. of the volume, which can contain oil, constituting a long-life bearing without the need for further lubrication. The powders, of correct grain size and quality, are mixed with a small quantity of powdered graphite, and sometimes a small amount of lubricant, to facilitate the pressing operation. On removal from the press, the compacts are strong enough to be handled, and are now heated for a short time at 750° – 850° C. in a furnace of bright annealing type, in which the atmosphere can be controlled so as to be reducing or neutral in character. In sintering, the tin melts, alloys in part with the copper, and leaves the pores or voids in question. After sintering, the bearings are impregnated with lubricating oil, either at 110° C. for 10–15 mins. soaking; or at lower temperatures in a vacuum chamber.

Positron, Symbol 0_1p . The positive electron, a positively charged nuclear particle with a mass equal to that of an electron, a charge probably exactly equal to that of a proton, a quantum spin equal but opposite to that of the electron (q.v.) and very great penetrating power. As a free particle, it is very short-lived, combining readily with an electron to give two or more quanta of radiation. P. may be produced in the artificial disintegration of a nucleus when a primary cosmic ray impinges on it; when the nuclei of certain light elements, as beryllium, boron and aluminium, are bombarded with α -rays from polonium; and (together with electrons, the p. representing about 7 per cent. of the total emission) when a narrow beam of γ -rays from Thorium C' is allowed to impinge on a sheet of lead. The production of the p. by the absorption of α -rays by aluminium is as follows:



showing the intermediate formation of radio-phosphorus. When a p. is emitted from a nucleus, it may be considered that a proton disappears from one state and a neutron appears in another.

Pot

Pot Annealing. See Box A.

Pot Quenching. A process of quenching carburized parts directly from the carburizing box or pot. (Prop. Std. Defn., A.S.T.M., 1942.)

Potassium. K. El. A.W. 39.096; At. No. 19; S.G. 0.86; M. Pt. 62.5° C. Soft silvery white lustrous alkali metal, rapidly tarnishing in air, owing to the formation of a film of oxide; reacts violently with water to form the hydroxide, with the evolution of hydrogen, which ignites. Occurs as *sylvite*, KCl; *carnallite*, $\text{KCl} \cdot \text{MgCl}_2 \cdot 6\text{H}_2\text{O}$; *saltpetre*, KNO_3 ; *alunite*, $3\text{Al}_2\text{SO}_4 \cdot \text{K}_2\text{SO}_4 \cdot 6\text{H}_2\text{O}$; *orthoclase*, $\text{Al}_2\text{O}_3 \cdot \text{K}_2\text{O} \cdot 6\text{SiO}_2$, and in many other minerals, plants, etc. Extracted by the electrolysis of fused caustic potash, KOH; or of a fused mixture of p. and calcium chlorides. A p.-sodium alloy, liquid at ordinary temperatures, is used for thermometers at temperatures above the boiling point of mercury (357° C.). P., like sodium, is a hardener in lead, and a British patent of 1925, covering lead-base bearing alloys, specifies the use of p. and sodium in equal proportions, with a maximum of 0.8 per cent. in each case, with up to 0.1 per cent. of lithium. The presence of p. has also been recorded in other alloys of this type.

Potential (Electrical). The p. at any point is the work required to bring to that point a unit positive electric charge from a region where there is absolutely no electric force, *i.e.*, a region at an infinite distance from any electrified body. See also **Electrochemical Series** and **Electrode Potential**.

Potential Difference (P.D.) between two points is the work done when a unit positive electric charge is moved from one point to the other. When p.d. causes a current to flow, it is termed **electromotive force (E.M.F.)**. Its unit is the volt.

Powder. In Powder Metallurgy, particles of matter in which the size and characteristics are of such an order as to make the material of use in the formation of compacts (A.S.M. Defn.).

Powder Compact. See Compact.

Powder Metallurgy (or Metal Ceramics). The art of producing metal powders and shaped objects from individual, mixed or alloyed metal powders, with or without the inclusion of non-metallic constituents, by pressing or forming objects which are simultaneously

or subsequently heated to produce a coalesced, sintered, alloyed, brazed or welded mass, characterized by the absence of fusion, or the fusion of a minor constituent only (A.S.M. Defn.).

Pre-Sintering. In Powder Metallurgy, the heating of a compact at a temperature below the normal final sintering temperature, usually to increase the ease of handling or forming the compact, or to remove a lubricant or binder prior to sintering (A.S.M. Defn.).

Precipitation Hardening. A process in which the re-heating of a supersaturated solid solution, obtained by quenching, leads to the precipitation of a structural constituent, with resultant increase in hardness.

Preece Test. A t. of the thickness and uniformity of coating on zinc-coated (galvanized) iron and steel parts. The solution contains 33 gm. of copper sulphate in 100 c.c. of distilled water and is neutralized by shaking with excess of cupric hydroxide, the s.g. being finally 1.170. The sample is subjected to 1-min. dips at 60° F., each followed by washing and brushing (to remove any copper deposit on the zinc coating) until, either it has withstood the required number of dips, or the end point has been reached, shown by the appearance of bright adherent copper deposit on parts of the iron base exposed by the removal of zinc.

Preferred or Preferential Orientation. An effect, shown on cold-working a polycrystalline mass, in which deformation is attended by a rotation of the slip planes in the different crystals so that they tend to conform with the deformation axis (q.v.). A p.o. may still be found after the recrystallization of a cold-worked metal on annealing; when, however, its direction may no longer be parallel with the deformation axis. The existence of p.o. leads to varying mechanical quality in different directions (*e.g.*, brass often shows lower strength and higher ductility at 45° to the direction of rolling), as is manifest in pressings made from such material. P.o. is also shown in fringe crystals (q.v.), where it arises in another manner. *See also Anisotropy, Directional Properties, Ears, etc.*

Preheating. (1) A general term used to describe a heating applied preliminary to some further thermal or mechanical treatment. (2) A term specifically applied to tool steel to describe a process in which the steel is heated slowly and uniformly to a temperature below the hardening temperature and is then transferred to a furnace in which the temperature is substantially above the preheating temperature. (Prop. Std. Defn., A.S.T.M., 1942.)

Pre

Press. (1) A machine used instead of a steam hammer for the forging of larger parts. It consists essentially of a cylinder, with a plunger or ram, moving vertically, and forced down by hydraulic pressure upon the part being shaped, supported upon a heavy anvil block. *See also P.-Forging.* (2) In Powder Metallurgy, a machine used to form a compact by pressure (A.S.M. Defn.).

Press-Forging. A process of forging by means of a hydraulic press instead of a steam hammer. The action is comparatively slow, but the pressure is applied for considerably longer periods, giving a proportionately better opportunity for plastic flow of the metal. The effect thus penetrates to the interior portions to an extent much greater than with hammer forging, and p.-f. is therefore much more suitable for larger work.

Pressed Bar. In Powder Metallurgy, a compact in the form of a bar (A.S.M. Defn.).

Pressing. (1) A particular type of drawing of sheet or strip metal, either cold or hot, by means of a press, fitted with the necessary holders, dies, punches, etc. Brass and copper are metals commonly pressed. Cups and many other shapes can thus be made, and the parts can be flanged, indented, embossed, etc. When an excessive amount of cold work is done, full or local annealing must be carried out. The risk of season cracking (q.v.) must also be avoided. (2) In Powder Metallurgy, the forming of a compact under pressure (A.S.M. Defn.).

Pressing Crack. *See Slip Crack.*

Pro-Eutectoid. A phase which continues to separate from a solid solution, on cooling, until the remainder has reached eutectoid composition. In hypo-eutectoid steels, the p.-e. is ferrite; and, in hyper-eutectoid steels, cementite. The p.-e. normally separates at the grain boundaries of the original phase. When this is of coarse grain, the p.-e. may also separate on the crystallographic planes. *See also Widmanstätten Structure.*

Process Annealing. A process commonly applied in the sheet and wire industries, in which an iron-base alloy is heated to a temperature close to, but below, the lower limit of the transformation range, and subsequently cooled. (Prop. Std. Defn., A.S.T.M., 1942.) The temperatures used are between 550° and 650° C., usually at the upper limit, because the ferrite—the preponderating constituent of this low-carbon steel—which has been distorted by cold working, is then recrystallized more rapidly, the steel being thus effectively softened.

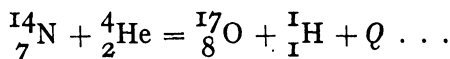
Proof Resilience. See Resilience.

Proof Stress. An arbitrary s. which, when applied to a tensile test piece for a specified period, and then removed, shall not have caused a permanent extension greater than the specified percentage, e.g., 0.1 per cent., of the gauge length. This test is often used for non-ferrous alloys and high-tensile steels, which do not show a yield point; and, for parts subjected in service to a steady s., it clearly constitutes a basis for arriving at the useful strength of a material.

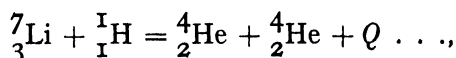
Proportionality Limit (Proportional Limit, Proportional Elastic Limit or Limit of Proportionality). The maximum static stress which a material is capable of developing without showing any deviation from the law of proportionality of strain to stress (Hooke's Law). This definition differs from that of the elastic limit (q.v.), but the p.l. is more readily determined, and is often accepted as the equivalent of the elastic limit.

Protective Atmosphere. See Controlled A.

Proton, Symbol ${}^1_1\text{H}$. The nucleus of the hydrogen atom, which has been stripped of its single outer electron. The p. is a nuclear constituent of all atoms. It has an atomic number of 1, a mass of about 1.0076 (as compared with 1.0081 for that of the free hydrogen atom) on the atomic scale; or 1.672×10^{-24} gm.; and a charge of 4.77×10^{-10} e.s.u., or 1.59×10^{-20} e.m.u. P. are produced by subjecting the nuclei of nitrogen and other elements to bombardment by α -particles, thus:



Having only half the charge of, with much more available energy than, the α -particle, the p. is a much more efficient atomic projectile. Subjecting lithium to the attack of an intense beam of p., to which a potential difference of 700,000 volts has been applied, leads to capture of the p., and disintegration as follows:



the two α -particles together possessing a kinetic energy in amount Q over and above that of the p.

Pseudomorphic Crystal (or Pseudomorph). A crystal which has assumed a geometric crystalline form other than its own.

Pud

Puddling Process. A p. for the conversion of grey pig iron into wrought iron by refining on the hearth of a coal-fired reverberatory furnace, which is lined (fixed or fettled) with ore or other material rich in iron oxides. The bath is stirred with a rabble to bring it into contact with the lining and also a current of air. The impurities are thus largely removed, either as gases or slags, from the metal. In principle, the p.p. is the same as the open-hearth process for the manufacture of steel, but it is conducted at a much lower temperature, insufficient to liquefy the reduced metal, which exists in pasty form. When this is collected together in the form of a ball, it still contains a proportion of intermingled slag, of which part only can be squeezed out under the hammer, the elongated threads of the residual slag imparting the characteristic fibre of wrought iron (q.v.).

Puffed Bar. In Powder Metallurgy, a cored bar expanded by internal gas pressure (A.S.M. Defn.).

Pulverization. In Powder Metallurgy, the reduction of metal to fine powder by mechanical means. *Disintegration* and *Comminution* are terms also used (A.S.M. Defn.).

Punch. (1) A tool or machine for making holes in metal by punching. (2) In Powder Metallurgy, the *lower p.* is the lower member of a die assembly which forms the bottom of the die cavity. It may or may not move in relation to the die. The *upper p.* is the member of a die assembly which moves into the die to transmit pressure to the powder contained in the die cavity. A *stripper p.* is a p., which, in addition to forming the top or bottom of the die cavity, later moves further into the die to eject the compact (A.S.M. Defns.).

Punching. The process of producing a hole in metal by driving through it a blunt-nosed instrument, the metal so displaced being almost entirely removed and forced out on the other side, only a small proportion forming part of the wall of the article. Cf. **Piercing.**

Pyrometer. An apparatus used in the measurement of temperature, particularly of that above the range of the ordinary mercury thermometer. The chief types of p., which may merely indicate the temperature; or may plot, either continuously or at intervals, a permanent record on a chart, are: (1) Thermo-Electric P. (range 400°–1400° C.), which determine the thermo-electric difference of potential resulting when one junction of two dissimilar metal or alloy wires changes in temperature, while the other remains at a constant temperature. (2) Electrical Resistance P. (range – 250°

to $+600^{\circ}\text{C.}$), which depend upon the fact that the electrical resistance of a metal increases, when heated, in a linear manner with temperature. (3) Radiation P. (range 800° – 2000°C.), in which the radiant heat from the hot body is concentrated, by means of a lens or mirror, on the hot junction of a minute thermocouple. (4) Electro-Optical P. (range 800° – 3000°C.), which utilize the fact that the intensity of light emitted by an incandescent body varies with temperature. These p. are photometers, which measure the brightness of the light coming from the hot body by matching it with a standard light, the adjustment necessary for this being calibrated to give a direct reading of temperature. (5) Purely-Optical P., which depend upon the same principle as the last, and have a similar range, but rely much more upon the judgment of the operator.

Q

Quality Refining. *See* Electric Steel.

Quality Values. V. which embody the results of tests of two different q. of a material, to obtain a numerical estimation of general mechanical q. Thus, if the tensile strength of a steel part is specified to be within a certain range, as 30–35 tons per sq. in., it may also be laid down that the sum of tensile strength in tons per sq. in., plus elongation per cent., determined on a standard test piece, shall be not below 57, a figure adopted by some classification societies in this country. A v. commonly employed in the U.S.A. is the tensile strength multiplied by the elongation per cent. on a standard test bar. The strength figure multiplied by the Izod figure is sometimes used. This method of combining the v. obtained by different tests is, however, evidently unsatisfactory, in that a low v. shown by one test may be masked when it is multiplied by a high one obtained in a test of an entirely different quality. The method of demanding minimum v. for each test which appears to be of significance in respect of the duty is clearly much more satisfactory. *See also* **Figure of Merit.**

Quantum (of electro-magnetic radiation). The fundamental unit of radiation, ϵ , which, for any wave-length, λ , or frequency, ν , is equal to hc/λ , or $h\nu$, respectively; where h is Planck's Constant (q.v.) and c is the velocity of light. Thus the energy of a q. differs with the kind of radiation, being greater as the w.-l. becomes shorter. A blue light q. has more energy than a red light q., and blue light is therefore more active chemically. Any excess energy of an isolated atom over and above the minimum value characteristic of the particular grouping of structural components will be radiated sooner or later as a q. (or several q.) of radiation. A q. may be emitted either from the nucleus or the extra-nuclear electron structure. Q. of γ -radiation are those emitted by nuclei. The energy of the q. is propagated with the velocity of light. *See also* **Radioactivity, Stationary States, etc.**

Quantum Numbers. N. which define the various elliptical orbits in which electrons can revolve round the nucleus. The energy levels corresponding with various possible orbits of revolution of successive electron "shells" round the nucleus are known as stationary states. According to the original Bohr Theory, the only stable stationary states are those in which the electrons revolve without the emission of radiation. Bohr further postulated that ν , the frequency of the

radiation emitted (or absorbed) when an electron jumps from one orbit to another, is given by the q. condition :

$$h\nu = E' - E''$$

where h is Planck's constant and E' and E'' are the energies of the two states. Stationary states are those for which the angular momentum is an integral multiple of $h/2\pi$. The general electronic orbit or state is thus $nh/2\pi$, where n is the principal q.n., a measure of the energy of the orbit, and always a whole number, from 1 to infinity, but in practice never greater than 7 or 8. In the original Bohr Theory, a subsidiary q.n., k , also a whole n., had to be introduced to cover an elliptical orbit, the ratio k/n being very approximately that of the minor to the major axis of the ellipse, thus determining its eccentricity. The new Q. Theory defines the electronic orbit by four q.n., n , l , m and s . Of these, the first or principal q.n., n , is as before; the second, l , replacing Bohr's k , equals $k - 1$, has any value from 0 to $n - 1$, and is a measure of the orbital angular momentum; the third, m , which may have any value from $-l$ to $+l$ (including 0), determines the component of the orbital angular momentum about some given axis, such as the direction of an applied magnetic field; while the fourth, s , determines the spin of the electron about its own axis and has two values only, $+\frac{1}{2}$ and $-\frac{1}{2}$.

Quarter-Hard. The amount of cold work that has been applied to brass sheet strip and foil (*i.e.*, the "temper" in which the material has been left) is expressed by the use of the terms: quarter-hard, half-hard, hard and extra-hard (*e.g.*, B.S. Spec. 265-267 : 1936), the correctness of the description being assessed by means of a cold bend test (B.S. Spec. 485 : 1934) of decreasing stringency as the material becomes progressively harder. The strength, ductility and hardness figures for each description are also specified, those for cold-rolled brass sheets, strip and foil (copper 61.5-64.0 per cent.) in widths up to 18 in., inclusive, being, for example, as follows :

| Temper | Tons/sq. in. (min.) | Elong. % (min.) | Hardness Nos. | |
|----------------|------------------------|--------------------|---------------|--------------------|
| | | | Brinell | Diamond Pyramid |
| Annealed . . | 18 | 40 | 75 (max.) | 80 (max.) |
| Quarter-Hard . | 22 | 30 | 70 (min.) | 75 (min.) |
| Half-hard . . | 25 | 15 | 100 (min.) | 110 (min.) |
| Hard . . . | 30 | 3 | 120 (min.) | 135 (min.) |
| Extra-hard . . | 34 | — | 150 (min.) | 165 (min.) |

Qua

For brass sheet and strip, A.S.T.M. Spec. No. B36—42T, covers the following tempers: Quarter-hard, half-hard, three-quarter-hard, hard, extra hard, spring and extra spring; corresponding to percentage reductions in thickness on rolling approximately as follows: 10·9; 20·7; 29·4; 37·1; 50·0; 60·5 and 68·7 per cent., respectively. Similar terms are used for cold-rolled steel strip, for which A.S.T.M. Spec. No. A109—38 specifies five grades or tempers, as follows: hard, half-hard, quarter-hard, soft and dead soft, with mean Rockwell B. hardness figures as follows: 90, 80, 69, 58 and 45, respectively.

Quasi-Isotropy. The simulation of isotropy presented by an aggregate of a sufficient number of metallic crystals, in which, in spite of the anisotropic nature of the individual crystals, the random orientation of the many crystals masks the directional effect in the mass as a whole, so that it appears to be isotropic in its mechanical properties.

Quaternary. Consisting of four components.

Quaternary Alloy. An alloy containing four principal elements (A.S.M. Defn.).

Quench Ageing. *See* Ageing.

Quench and Fracture Test. A determination of grain size and hardenability, made by heating normalized sections of steels above the A_c point, quenching at intervals of 30° C., and comparing with standard fractures.

Quench-Tempering. The processes of quenching and tempering combined in one operation, the part being quenched from the appropriate temperature in a bath; for example, an oil bath, which is held at a suitable tempering temperature. The part is allowed to remain in the bath for some 15 mins.; or long enough for it to reach bath temperature, when it is withdrawn and allowed to cool normally. Although the process obviously has some applications, the hardness obtained by this combined operation is much less than is obtained by quenching, followed by tempering, in the usual manner.

Quenching. Rapid cooling from an elevated temperature by immersion in a liquid bath, as of oil or water, so as to withdraw heat rapidly from the part being quenched. The purpose of q. is to suppress a phase transformation or a disorder/order change (*see Solid Solution*), so as to obtain increased hardness, or other desirable properties. The severity of the quench depends upon the capacity,

of the bath to withdraw heat rapidly from the metal, this in turn depending upon the latent heat of vaporization, the thermal conductivity, the specific heat, and the viscosity of the liquid. The air hardening (*i.e.*, air-q.) of certain alloy steels is, in principle, exactly the same process.

R

Radiate Structure. The type of s. produced by crystallization outwards from a centre, as shown by pure metals and various eutectics.

Radioactivity. An atomic phenomenon, characterized by the emission of radiation, attending the transformations of an original unstable radioactive element through a number of states, in each of which the temporary substance formed has all the characteristics of an "element" (q.v.). Radioactive elements, such as radium and thorium, are continuously transmuting themselves spontaneously into other elements having atoms of lesser mass, the nuclei of which, being left in an excited state, rapidly emit their excess energy in the form of α -, β - or γ -particles (q.v.). All three types of radiation affect a photographic plate, render certain materials—as zinc sulphide—fluorescent, and lead to the ionization of gases. While early experiments in atomic bombardment (Rutherford, 1919) had produced only stable isotopes of other elements, F. Joliot and his wife, Irene Joliot-Curie, discovered in 1934 that the radiation emitted when aluminium and other light elements were bombarded with α -particles continued to be emitted after bombardment had ceased. This artificial r. was found later to be due to the emission of positrons (q.v.), instead of the electrons emitted from naturally radioactive substances. *See also Transmutation of Elements*, etc.

Radiograph (or Skiagraph). An X-ray photograph. The term, radiogram, is also used; but this has already two other meanings: (1) the combination of radio-receiver and gramophone, (2) a telegram transmitted by radio; and it should clearly not be used in the present sense.

Radiography. The examination of the internal soundness of metallic and other bodies by means of X-rays or gamma rays ("short" X-rays). Radiation passing through cavities, cracks or inclusions is absorbed to a lesser degree than when passing through the adjacent sound metal, the position and extent of the particular defect being determinable by tests made from a sufficient number of alternative positions. Gamma rays are more penetrative, and, the source being relatively small, can be used in places quite inaccessible to an X-ray equipment. In practice, a photographic film is usually placed so as to intercept the emergent beam, the internal defect being revealed on development as an area of greater photographic density. This can also be observed, although much less effectively,

by viewing with a fluorescent screen. *See also X-Ray Tube, X-Rays, etc.*

Radiology. (1) That branch of science which concerns radiant energy and its physical laws and applications. It embraces radiography, X-ray crystal analysis, etc. (2) The term is often used in a restricted sense to denote the applications of radiant energy specifically in medicine.

Radium. Ra. El. A.W. 226.05; At. No. 88; M. Pt. 700° C. Brilliant-white radioactive metal, turning black in air, from the production of a nitride; and rapidly attacked by water, with the formation of a hydroxide and the evolution of hydrogen. Occurs in minute quantities in pitchblende, carnotite and all ores of uranium. Extracted from pitchblende by a complex and laborious process involving repeated recrystallization of barium and r. chloride, the latter being less soluble. Obtained by the electrolysis of r. chloride, using a mercury cathode, from which the mercury is distilled off at 500° C., to leave the pure r. Used in luminous paint for industrial dials, in therapy, and to replace X-rays in radiography.

Rare Earth Metals. A group of widely-distributed metals, comprising scandium (at. no. 21), yttrium (at. no. 39) and the 15 elements of at. no. 57 to 71, inclusive. These have the same arrangement of the two external shells of electrons in their atoms, and resemble one another very closely in chemical and physical properties, being thus most difficult to separate from each other. It is to this rather than their actual rarity in nature that they are so described.

Real Fracture Stress. *See True Tensile S.*

Recalescence. A heat evolution attending the austenite → pearlite transformation at A_{r1} . With high-carbon steels, the r. is such as to make the steel—viewed preferably in the dark—become visibly hotter. This is only one example of a more general phenomenon. (*See under Metastable Equilibrium.*)

Recarburization. The addition, in some form or other, of the appropriate quantity of carbon to metal, *e.g.*, steel, which has been partly decarburized in a previous refining process, so as to obtain the correct proportion of carbon in the final alloy. *See Open-Hearth Process.*

Rec

Recrystallization. The substitution of one crystal structure by another, as occurs on heating or cooling through a critical temperature. The term is also sometimes applied to the process of development of new crystals on annealing severely cold-worked metals, in which the original crystal structure has been to a large extent destroyed. Thus, cold-worked lead recrystallizes rapidly on annealing at 200° C., to a considerable degree on heating for 30 mins. at 100° C., and in time even at atmospheric temperature. *See also* **Heat Refining, Grain Refinement**, etc.

Recuperative Furnace. A f., of usual reverberatory f. type, in which, however, the incoming air is pre-heated by being passed through pipes traversing the exhaust flue of the f. Other types of f. may also utilize the same principle. *Cf.* **Regenerative F.**

Red-Hardness. A term sometimes used to denote the quality, shown by high-speed steel (q.v.), of maintaining a cutting edge at a red heat; when a tool of ordinary carbon steel would become so tempered as to be useless.

Red Heat Range. A somewhat indefinite temperature r., covering temperatures from that of a just visible red (about 525° C. when viewed in the dark) to a full cherry red (about 900° C.). *Cf.* **Black H.R.**

Red Shortness. Lack of ductility in steel at a red heat, as may be assessed by a bend test made at such a temperature. R.s. is shown by steels containing too much sulphur and insufficient manganese, when brittle membranes of iron sulphide (FeS) may occur at the grain boundaries. If the manganese content is three to four times that of the sulphur, so long as the oxygen content does not exceed 0.04 per cent., this effect is prevented. In commercial steels of the present day, where the manganese content is usually some fifteen times that of the sulphur, and the oxygen content is below 0.10 per cent., r.s. cannot occur. *See also* **Burning**.

Reduction of Area (or Contraction of Area). A measure of ductility, determined on a standard tensile test piece by the percentage reduction of the cross-sectional area at the fracture, as compared with the original area.

Reeds. Surface defects in steel blooms originating as subcutaneous blowholes—as may result from reactions between the metal and the mould during solidification—which become oxidized in soaking prior to rolling, and are elongated in this operation. R. may give rise to cracks which extend more deeply.

Reeled Bar. *See* Reeling.

Reeling. A finishing process applied to a round bar, previously hot-rolled as usual, in order to make it perfectly straight, remove surface scale and impart a high polish. Instead of the usual longitudinal rolling, r. is effected by rolls (*e.g.*, one on top and two beneath) which revolve at right angles to its length.

Refined Bar Iron (or Refined Wrought-Iron Bars). Iron bars rolled from a muck bar pile or from a box pile, of muck bars and wrought-iron scrap bars free from steel, all bars running the full length of the pile. (A.S.T.M. Stds., A81—33.)

Refining. (1) Any process in which impurities are removed from a metal or alloy, in order either to improve its quality, or to obtain a different product. (2) Grain Refinement (*q.v.*). *See also* Heat R.

Refining Temperature (or Heat). A temperature employed in heat treatment to refine the structure, in particular, the grain size. Usually just above A_{c_3} in steel (A.S.M. Defn.).

Regenerative Chamber (or Regenerator). A c. filled with open-work "checker" brickwork (brickwork of refractory clay alternating with space), by means of which the otherwise waste heat contained in the products of combustion of the Siemens open-hearth furnace is first collected and then used to pre-heat the incoming producer gas and air, thus serving to maintain furnace temperature and accelerate the reactions. There are two c. on each side of, or underneath, the furnace, a smaller one for gas and a larger one for air in each case. The flow through the r. is reversed at appropriate intervals by means of a valve.

Regenerative Furnace. A f. equipped with r. chambers (*q.v.*).

Regenerative Quenching. A double quenching of carburized objects to refine the case and core. The first quench is from a high temperature to refine the core and the second quench is from a lower temperature to refine and harden the case (A.S.M. Defn., slightly modified).

Regular System. *See* Cubic S.

Repeating Compound. A solid carburizer which, instead of once only, may be used again and again.

Res

Residual Stresses. See Internal Stresses.

Resilience. (1) As generally understood, the power of an elastically-strained body to spring back on removal of the load. (2) Strictly, the potential energy stored up by an elastically-strained body, and restored when the load is removed. Within the elastic limit, this is the product of half the load and the extension. The *proof r.* is the greatest amount of energy that can be stored up by a body strained only elastically. If p is the uniform stress at the elastic limit of the material, and E the stretch modulus, the proof $r.$ is $\frac{p^2}{2E}$ per unit volume. The *modulus of r.* or *unit r.* is a measure of the capacity of a body to absorb shock elastically, and is the greatest amount of elastic energy that can be stored up in unit volume of the material.

Restrainer. See Inhibitor.

Reverberatory Furnace. A f. in which the melt is subjected to the action of flame but does not come into actual contact with the fuel. The flame enters from the side, or end, is directed, by means of a low wall, or bridge, upwards against the roof, and is then deflected downwards upon the melt.

Reversible or Balanced Reaction. R. which is not completed, because, under the particular conditions of temperature, volume, pressure or quantities of reacting substances, the original substances are reacting with each other to form new ones at the same rate as these are reacting to reproduce the original ones. By suitable variation in one or more of these conditions, the r. can be made to proceed in either direction.

Reversible Steels. See Irreversible S.

Rhenium. Re. El. A.W. 186.31; At. No. 75; S.G. 21.2; M. Pt. 3440° C. A powder resembling those of tungsten or osmium, oxidizing only at high temperatures and very resistant to corrosion. Occurs in very small quantities in *columbite* and in platinum and molybdenum ores. Obtained by the reduction of potassium per-rhenate, $KReO_4$, or the oxides or sulphides, on heating in an atmosphere of hydrogen. A metal not yet in industrial use, but with considerable possibilities. Thus, it can readily be plated on copper, brass, etc., in any thickness required, and has great throwing power; while the deposit is highly resistant to hydrochloric acid, suggesting its use for drums and tanks for transport of this acid.

Rhodium. Rh. El. A.W. 102.91; At. No. 45; S.G. 12.1; M. Pt. 1966° C. Bluish-white metal resembling silver, but harder; malleable and ductile when pure; very resistant to temperature and corrosion attack. Occurs native, associated with platinum. Obtained as a by-product in the extraction of platinum from residues from electrolytic nickel and copper refineries. Separation of the various platinum-group metals from each other is complex and lengthy. Used as an electro-deposited coating on brass, bronze, copper, silver, nickel and most nickel alloys; and for surfacing metal reflectors, where r. has a higher specular reflection over a wider range of colour than any other reflector material. Platinum-r. alloys (10–13 per cent. r.) are used as one component of high-temperature thermocouples, the other being pure platinum; they are not only more robust but also more resistant than pure platinum for laboratory crucibles, etc.; and they are also used for magneto contacts and spinnerets in the rayon industry.

Rigidity (or Stiffness). That quality by virtue of which a material resists change of form when subjected to the action of external forces. The magnitude of Young's Modulus in tension, or the corresponding ratio of stress to strain in shear (Modulus of R., or Shear Modulus) are measures of the r. of a material. R. is not synonymous with brittleness, although often confused with it. Nor is it the same quality as hardness, for mild steel, although much softer, possesses, as measured by Young's Modulus, more than twice the r. of ordinary cast iron. R. is much the same for all steels, and cannot be controlled by mechanical or thermal treatment.

Rimming Steel (Rimmed or Effervescing Steel). Low-carbon s., which has only partially been deoxidized, in a controlled degree. Such s., by reason of the reaction between carbon and ferrous oxide, giving rise to carbon monoxide gas, is effervescent when cast and during a good deal of its solidifying period. This liberation of gas in the semi-solid mass—and consequent increase in the nominal volume of the solidified s.—is controlled so as just to make up for the normal shrinkage on solidification, thus avoiding the production of the central cavity, or pipe, found in killed s. ingots. The discard from a r.s. ingot is thus much less and the yield proportionately greater. The term, r., describes the effect seen on the top surface of an effervescing ingot on solidification, where there is a gradual "rimming in" from the sides inwards, the residual liquid portion becoming gradually smaller, until the whole is solid. Again, a cross-section through the ingot reveals a well-defined outer case or rim, which may be very thin or very thick, is of practically the same composition as the s. being poured, and is free from blowholes. These are confined to the interior, particularly to a zone just inside

Ris

the rim and at a uniform distance from the surface. The surfaces of the blowholes are not oxidized and they therefore very largely weld up during the subsequent rolling of the ingot, giving a product quite suitable for less important duties.

Riser. An enlarged upper projection on a casting, where, by reason of the mass, solidification is much delayed, thus providing a reservoir of liquid metal which is fed down to replace the volume lost during solidification, a sound casting being thus produced. The r. is finally removed.

Roak. *See* Roke.

Rockwell Hardness Test. A t. which measures hardness by determining the depth of penetration of a penetrator into the specimen under certain arbitrarily fixed conditions of test. The penetrator may be either a steel ball or a diamond sphero-conical penetrator. The hardness value, as read from the dial, is an arbitrary number which is related to the depth of indentation, and, since the scales are reversed, the number is higher the harder the material. A minor load of 10 kg. is first applied which causes an initial penetration which sets the penetrator on the material and holds it in position. The dial is set at zero on the black-figure scale, and the major load is applied. This major load is customarily 60 kg. or 100 kg. when a steel ball is used as a penetrator, but other loads may be used when found necessary, and usually 150 kg. when a diamond sphero-conical penetrator is employed. The ball penetrator is $\frac{1}{16}$ in. in diameter normally but other penetrators of larger diameter such as $\frac{1}{8}$ or $\frac{1}{4}$ in. may be employed for soft metals. A variety of loads and penetrators are thus provided and experience decides the best combination for use. After the major load is applied and removed, according to standard procedure, the reading is taken while the minor load is still in position.

R.h. values shall be determined and reported according to one of the standard scales specified in the table (page 181).

In all cases the minor load shall be 10 kg. and the dial shall be adjusted after applying the minor load so that the pointer reads at "set". (A.S.T.M. Stds., E18—42.)

Rod. Steel rolled in a coil, of size smaller than bar (q.v.), and usually from $\frac{7}{16}$ in. down to $\frac{3}{16}$ in., the smallest diameter that can economically be produced by rolling.

Roke (or Roak). A longitudinal crack or seam on the surface of forged or rolled steel, resulting from the elongation of a surface defect in the original ingot. The initial defect is often a superficial or

| Scale Symbol | Penetrator | Major Load, kg. | Dial Figures |
|--------------|--------------------------|--------------------|--------------|
| GROUP ONE | | | |
| B | $\frac{1}{16}$ -in. ball | 100 | Red |
| C | " Brale " | 150 | Black |
| GROUP TWO | | | |
| A | " Brale " | 60 | Black |
| D | " Brale " | 100 | Black |
| E | $\frac{1}{8}$ -in. ball | 100 | Red |
| F | $\frac{1}{16}$ -in. ball | 60 | Red |
| G | $\frac{1}{16}$ -in. ball | 150 | Red |
| H | $\frac{1}{8}$ -in. ball | 60 | Red |
| K | $\frac{1}{8}$ -in ball | 150 | Red |
| GROUP THREE | | | |
| L | $\frac{1}{4}$ -in. ball | 60 | Red |
| M | $\frac{1}{4}$ -in. ball | 100 | Red |
| P | $\frac{1}{4}$ -in. ball | 150 | Red |
| R | $\frac{1}{2}$ -in. ball | 60 | Red |
| S | $\frac{1}{2}$ -in. ball | 100 | Red |
| V | $\frac{1}{2}$ -in. ball | 150 | Red |

subcutaneous blowhole, which may be attended by segregation and decarburization; and is sometimes a crack, resulting from uneven cooling, or in some other manner. The presence of a r. involves the possibility of a dangerous extension during subsequent operations. A longitudinal defect in rolled metal caused by the rolls is a fold in the metal, so as to enclose surface scale, and should not be described as a r., but a lap (q.v.).

Roll Compacting. The progressive compacting of metal powders by the use of a rolling mill (A.S.M. Defn.).

Roll-Forge Process. A process in which round or square steel bars, heated to rolling temperature, are reduced and formed as they pass between two formed rolls, and are at the same time rolled in a transverse direction in much the same manner as a pencil is rolled between the palms of the hands. A bar being roll-forged is essentially rolled in two directions at the same time, the product becoming concentric and being made to conform to the cross-section which is embodied in the roll faces.

Rolling. A process of reducing ingots to smaller sizes—blooms, billets, bars, rods, sections, slabs, plates, sheet, etc.—by passing between two heavy cast iron or alloy steel rolls, which exert a com-

Rol

pression for a short period; while at the same time the rotation of the rolls, in opposite directions, advances the metal continuously. The rolls are plain cylinders for slabs, plates and sheets; but are grooved for blooms, billets, bars, rods and sections. R. elongates the metal only in one direction, except for a slight lateral spread. The directional properties thus set up may be counteracted in sheets by rolling in two directions at right angles. Hot r. of steel is r. above the A_c point, resulting in grain refinement, and the directional banding of inclusions and segregated regions. The tensile strength is unaffected in all directions, but the ductility and Izod values increase in the direction of r., and fall off transversely to this. Cold r. leads to a distortion of the grain structure in the direction of r., with a parallel increase in yield and ultimate stress values, and a corresponding decrease in ductility. The maximum change in tensile properties is found in the range up to a total elongation of 1.5 per cent., corresponding to a reduction of $33\frac{1}{3}$ per cent. in the original thickness. Further elongation beyond this value has much less effect.

Rolls. In Powder Metallurgy, a machine used to apply pressure progressively to form a compact (A.S.M. Defn.).

Ropiness. A quality of steel characterized by the occurrence of lateral fractures in ingots being rolled down.

Rough-Turning. A method of removing superficial defects in steel billets or ingots by turning them in a lathe. The same method is employed in removing the surfaces of steel castings to reveal the presence of defects.

Rubidium. Rb. El. A.W. 85.48; At. No. 37; S.G. 1.525; M. Pt. 38.5° C. Silvery-white alkali metal, decomposing water with the liberation of hydrogen. Occurs in small quantities widely distributed in nature, in *lepidolite*, *carnallite*, *mica*, *orthoclase*, etc. Obtained, with caesium, by a complex wet process, from artificial carnallite, a by-product in the extraction of potassium from carnallite. In the pure state, r. is obtained by the electrolysis of the fused hydroxide. Used in the manufacture of photo-electric cells.

Runner (Gate or R. Gate). The portion (or portions) of a mould through which molten metal is led into the space giving shape to the casting. A r. usually consists of a larger *down-r.*, to provide an adequate supply of liquid metal; and an *in-gate*, of smaller area—and thus constantly supplied with metal—leading into the mould proper.

Running Quality. See **Flowing Power.**

Rusting. A term, restricted to iron and its alloys, denoting atmospheric or other corrosion attack, accompanied by the formation of a brown or reddish surface layer of *rust*, composed of ferrous and ferric hydroxides, the first being probably the initial product, which is converted by further oxidation into the second. The composition of rust varies with the conditions of its formation. On drying, rust loses water, and is largely converted into ferric oxide (Fe_2O_3); while in some circumstances magnetic oxide of iron (Fe_3O_4) is also present.

Ruthenium. Ru. El. A.W. 101.7; At. No. 44; S.G. 12.26; M. Pt. 2450°C . Greyish-white lustrous hard and brittle metal, very resistant to corrosion. Occurs native, associated with the other platinum metals. Obtained as a by-product in the extraction of platinum from residues from electrolytic nickel and copper refineries. Used in place of iridium as a hardener for jewellery platinum. A 10 per cent. r.-platinum alloy is used for contacts for high-tension magnetos, voltage regulators, thermostats and relays. R.-palladium alloys are being increasingly used for white jewellery.

S

S-Curves. Curves representing the process and result of austenite transformation at constant temperature, *i.e.*, the relation between the time of transformation and the temperature at which this occurs. When a steel, previously made austenitic, is held at a constant temperature below that at which the austenite is completely stable, transformation is not instantaneous, but requires, for its onset and for its completion, definite periods which are characteristic, for a given steel, of the temperature level at which the steel is being held. The S-c., two in number, meeting at the top and bottom, but separated laterally by varying distances, each representing the time of transformation at the particular temperature, is a temperature-time diagram plotted on a logarithmic scale, to allow for the maximum period of a month or more, which may be required before transformation is complete. S-c. are determined by quenching specimens of the steel from above the transformation temperature in liquid baths held at various temperatures below this temperature, allowing the specimen in each case to remain in the bath until transformation at the particular temperature is complete. This may be determined either by recording the volume changes continuously with a dilatometer; or by quenching in water, so as to convert into martensite any austenite previously unchanged. Considerable information is thus obtainable as to the structural changes which occur in the quenching of steel. *See also Austempering, Critical Cooling Rate, etc.*

Safety, Factor of. *See Factor of Safety.*

Sandberg Sorbitic Treatment. A treatment in which carbon steel objects are moderately hardened, either wholly or in part. It consists in cooling the parts to be hardened through the transformation range at a moderately rapid rate by the application of jets of air, steam, or atomized water and then allowing the residual heat in the object to effect a tempering operation. (Prop. Std. Defn., A.S.T.M., 1942.)

Sankey Test. A reversed bending t., applied usually to steels, in which the t. piece, held at one end in the grip of a strong cantilever spring, is bent backwards and forwards manually through a standard angle on each side of its normal position until it breaks. The total energy to cause fracture is autographically recorded. The quality of different batches of supposedly similar material can thus be compared.

Saturation Point. (1) For a liquid solution, the maximum possible concentration of the solute at the given temperature. (2) For a solid solution of one metal in another, the maximum concentration which can be reached without the appearance of a second constituent.

Scab. (1) On castings, a rough projection, usually porous and containing embedded sand, due to the mould or core being insufficiently rammed, insufficiently bonded, or over-baked; so that it does not withstand the wash of the liquid metal; a piece of the sand may even break away. (2) On ingots, portions of a shell that is present near the bottom of all top-cast ingots; or of a skin that may be found on any part of an ingot improperly poured. A shell is formed round the base of the ingot from the first splashes of metal striking the mould stool. The production of a s. is avoided if the nozzle is large enough for the molten metal to rise in the mould so rapidly as to reach the top of the shell before this has become cold and oxidized. (3) On plates, etc., a defect where the skin of a blowhole has been only partly burnt away, but is not welded to the rest of the metal, and can be removed by hammering.

Scaffolding. *See* **Bridging.**

Scale. An adherent oxide layer produced on the surfaces of metals and alloys when heated under oxidizing conditions. The term applies usually to steel, where the s. varies in composition, the outermost showing the highest and the innermost the lowest oxygen content. S. produced below the iron-magnetic oxide eutectoid separation point, 575°C. , shows two layers only, an outer one of ferric oxide (Fe_2O_3), and an inner one of magnetic oxide (Fe_3O_4). Ferrous oxide (FeO) is produced only at a higher temperature, increasing in thickness with temperature. Pickling (q.v.) dissolves this inner layer, when the outer layers of ferric and magnetic oxides become detached and fall to the bottom of the tank.

Scales (or Shells). Defects found on the surface of a steel ingot, usually towards the base, after stripping. S. are due to the adhesion, to the mould surface, at an early stage in pouring, of splashes of oxidized metal. They are more readily shown on macro-etching, and may originate cracks during later treatment.

Sclerometer. *See* **Scratch Hardness Test.**

Scleroscope. An instrument by means of which the hardness of a plane surface is determined by the height of first rebound of a diamond-pointed hammer falling freely from a height of 25 cm.

Scr

down a vertical glass tube graduated into 140 equal divisions. The value obtained depends to a considerable extent upon the elasticity of the material, and the test is not suitable for comparing the hardnesses of different types of material. For any one class of material, as steel, however, a close parallel is obtained with the results of the Brinell test. The s. is used chiefly for testing very hard surfaces, particularly case-hardened parts.

Scratch Hardness Test. (1) A h.t. in which the material to be tested is suitably rubbed against another of known hardness, the softer material being marked by the harder. Mohs thus arranged ten minerals in order of ascending h. : (1) talc, (2) gypsum, (3) calcite, (4) fluorite, (5) scapolite, (6) felspar, (7) quartz, (8) topaz, (9) sapphire, (10) diamond. This scale is sometimes used by mineralogists, but it is not precise enough for metals and alloys. (2) A s.h.t. which can be used for metals and alloys utilizes a *sclerometer*, of which there are several types. In one, a s. is made with a hardened point, using a fixed load, either the width of the s. being measured, with a calibrated microscope, or sometimes the depth. S. resistance may be defined as the quotient of the load in kilograms divided by the width of the s. in millimetres. In another method, the load is variable, and one determines the load in grams (the "hardness number") at which a "normal" s. (*i.e.*, one just discernible as a dark line on a bright surface) is obtained. The test has little vogue in this country.

Seam. (1) A crack on the surface of forged or rolled material which has been closed but not welded ; usually resulting from blow-holes in the original ingot. In rolled material, s. vary in depth and are generally parallel with the direction of rolling. In forged material, s. usually follow the contour of the forging. If very fine, a s. may be called a hair crack or hair s. The presence of s. is prejudicial, in that they may open up into deep hardening-cracks during heat treatment ; or may set up fatigue failures in service (*see Stress Raisers*). (2) The term is sometimes used to describe the defect properly known as a lap (q.v.), its use in this sense being unnecessary and undesirable.

Season Cracking (or Corrosion C.). An apparently spontaneous intercrystalline c. of cold-worked brasses and other alloys, on standing, due to the residual stresses left in the material after cold working, and the aggravation of these by corrosion. The residual stresses may be tensile in some layers of the material, balanced by compressive stresses in others, the s.c. occurring in external layers which are in tension. The liability to s.c. can be determined by immersion for a few minutes in a solution containing 1 per cent.

each of mercurous nitrate and nitric acid ; when, if no c. occurs on standing for 24 hrs., the part is substantially free from internal stresses. S.c. may be prevented by a suitable stress-relieving treatment, *e.g.*, annealing for 20 mins. at 300° C. for brass. *Cf.* **Caustic Embrittlement.** *See* **Intercrystalline C., Internal Stresses, etc.**

Seasoning (or Weathering). A mode of treatment of iron castings, which are allowed to remain in storage, or to stand out in the open, for a more or less extended period, *e.g.*, 6 months, in order to effect a reduction in the residual stresses and consequently in the degree of distortion during subsequent machining. A very similar result can often be obtained by a comparatively short period, *e.g.*, 30 mins., of tumbling (q.v.). Since stress-relieving (q.v.) by heat treatment is a more certain process, and seasoning involves much delay and the use of considerable space for storage, stress-relieving is more usually employed.

Secondary Hardening. Hardening produced by tempering, usually of quenched high-speed tool steels. On tempering these at 400°–600° C., any austenite retained by quenching is converted into the harder martensite.

Seebeck Effect. The thermoelectric difference of potential (E.M.F.) set up in any circuit composed of two dissimilar conductors, if the two junctions are at different temperatures. *See* **Thermoelectric Power.** *Cf.* **Thomson and Peltier E.**

Segregation. The tendency of any constituent separating from a mass of solidifying metal to collect in greater proportion in some regions than in others, the portions last to solidify containing a higher proportion of the more readily fusible constituents. Thus, in the solidification of a mass of molten steel, as in the freezing of an ingot, the crystals deposited earlier are purer, and the residual liquid becomes increasingly impure, this effect giving rise to major s., the axial and upper portion of the ingot containing a higher proportion of constituents of low melting point. Minor s. results from the trapping of small pools of liquid between the growing crystals, an effect which may be found anywhere in the ingot. The degree of s. decreases as the time for complete solidification increases, affording greater time for the solid and liquid phases to achieve a correct balance. Again, annealing for a sufficient time at a temperature below that of the solidus will enable the alloy to become completely homogeneous, this requisite annealing period varying greatly with different alloys. *See also* **Ghost, Inverse S., etc.**

Seizing. *See* **Galling.**

Sel

Selenium. Se. El. A.W. 78.96; At. No. 34; Metalloid, closely resembling sulphur in chemical properties, and existing in several allotropic forms, one of which is the silvery-grey "metallic" s., occurring in lustrous hexagonal crystals (m. pt. 217° C.). Occurs as various metallic selenides, often associated with sulphides, *e.g.*, in pyrites; and commonly found in the flue dust of the pyrites burners used in the manufacture of sulphuric acid. Extracted largely as a by-product from copper-refining processes, where the anode slimes often contain considerable proportions of s. The electrical conductivity of metallic s. varies instantaneously on exposure to light, this property being used, in the s. cell, for the automatic lighting and extinction of marine lights, telegraphing of photographs, reproduction of sound records on cinema films, etc. S. is also used in the manufacture of rectifier discs; in low proportion (0.0018–0.007 per cent.) to decolourize bottle glass, in higher proportions (1.5 per cent.) to give a reddish tint to table glass and (2–3 per cent.) a deep ruby colour to signal glasses; as a catalyst in fat hardening; in vulcanization, the manufacture of dyes and medicines, and as a free-machining addition in 18:8 stainless steels and copper alloys.

Self-Annealing. (1) An effect, also known as "spontaneous a.", shown by cold-worked metals of low melting point (*e.g.*, lead), which recrystallize and soften in time when kept at atmospheric temperature, the facility with which s.-a. is effected increasing with the purity of the metal. Thus lead containing only 0.0012 per cent. of total impurities, reduced in section 5 per cent. by rolling, becomes completely recrystallized on a. for 1½ hrs. at 18° C., but with 0.0082 per cent. of impurities remains unchanged on so a. Again, the occurrence of s.-a. also requires a minimum degree of critical strain (q.v.) in the material. (2) An effect shown by cast aluminium bronzes of heavier section which have been cooled slowly from temperatures over 600° C., when the β -constituent is completely resolved into the $\alpha + \delta$ eutectoid, showing a coarse structure, associated with low strength and ductility. On quenching and tempering, the β -decomposition product is β_1 , a striated acicular constituent, associated with much better mechanical quality. S.-a. is also prevented by the addition of 1–3 per cent. of iron to the alloy, giving rise to a fine-grained structure of excellent mechanical quality, even after slow cooling.

Self-Diffusion. The movement of atoms through a lattice in which all atoms are identical, migration occurring simply by exchange of position.

Self-Hardening. See Air-Hardening.

Self-Stifling Reaction. A corrosion attack in which the corrosion product tends to form a surface layer protective against further attack. Thus, zinc is attacked vigorously when hydrochloric acid gas is dissolved in benzene free from water, but the reaction dies away as it proceeds, because the layer of zinc chloride is only very slightly soluble in benzene. If water is added, however, the zinc chloride dissolves, and the reaction proceeds once more. *Cf.* **Passivity.**

Semi-Finished Steel. *See* **Finished Steel.**

Semi-Killed Steel. S. containing about 0.06 per cent. of silicon, and therefore intermediate in character between Killed and Rimming S. (q.v.).

Semi-Polar Double Bond. *See* **Electronic Theory of Valency.**

Semi-Steel. A refined cast iron, in the manufacture of which some proportion of steel is used, the chief objects being to reduce the contents of carbon and phosphorus in the charge. Cast iron of good mechanical quality can thus be made more cheaply than by using low-carbon pig iron and scrap. The identity of the steel is completely lost after carburizing and melting in the cupola, and the quality of the iron may be poor or indifferent if the proper technique is not employed. The term, s.-s., implying a product intermediate in properties between those of cast iron and steel, is most misleading, and it should be regarded as obsolete.

"Shape-Strength" Tests. (German *Gestaltfestigkeitversuchen*.) T. in which the absolute or relative fatigue strength is determined by alternating stress t.; and the stress distribution by stress measurements on models or finished parts. Such t. are based upon the fact that the fatigue strength of a part in service is dependent not only upon the material used and the cross-section stressed, but also upon the design of the part. The relative advantages of using stronger material or of altering the design are thus determinable.

Shatter-Cracks. *See* **Flakes.**

Shear Steel. A type of cutting steel, originally used for cloth cutter's shears—from which the name is derived—and still employed for the best carving knives, etc. It is made by piling and forging together cemented bars (blister steel) some 18 to 20 in. long, the product being known as *single* shear steel. When a superior and more uniform quality is required, the hammered single shear bar is broken through the centre, doubled back on itself, re-heated and

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re-forged to the size required, the product being now termed *double shear steel*.

Sheet. A flat piece of steel or other metal obtained by rolling (q.v.), and usually not over $\frac{1}{8}$ in. in thickness; although, in some classifications, including the $\frac{1}{16}$ in. thickness. *Cf. Plate.*

Shells. *See Scales.*

Shepherd P-F Test. A test for hardenability (q.v.), in which one measures, either by fracture or by etching, the thickness of a flat plate which just fails to show an unhardened core.

Sherardizing. A process for obtaining a corrosion-resistant coating on iron and steel parts, particularly nuts, bolts, screws and the like. These are embedded in zinc powder ("zinc dust"), kept open by means of a small proportion of fine sand, the mixture being held in sealed containers and heated to 350°–400° C. for about 3 hrs., a protective surface layer of zinc-iron alloy being thus formed.

Shock-Testing. *See Impact T.*

Shore Scleroscope Test. *See Scleroscope.*

Short. *See Shortness.*

Short Cycle Annealing. A term usually applied in the modern a. of malleable cast iron, but strictly applicable to every cycle or furnace type that can reduce the total a. time necessary in a furnace of older type. Such reduction can be effected by employing a modern furnace of controlled, uniform and higher temperature, with a regulated protective atmosphere, making the use of packing materials and containers unnecessary, reducing the size of the batch and increasing the silicon content of the cast iron. Thus, an a. time of seven days in an old-type batch furnace fired with powdered fuel can be reduced, say, to 15 hrs. overall in a modern electric continuous furnace.

Shorterizing. *See Flame-Hardening.*

Shortness. Lack of ductility in metal.

Shot. In Powder Metallurgy, metal powder particles of spherical shape, usually solid (A.S.M. Defn.).

Shot-Blasting. A method of cleaning the surfaces of metal parts, chilled iron shot being hurled against the surfaces by a high-pressure air blast.

Shotty. Of a casting showing the defect known as Cold Shot (q.v.).

Shrinkage. Contraction in volume of liquid metal, or length of solid metal, on cooling. There are three well-defined varieties : (1) Liquid s., the contraction in volume as the metal cools from a higher temperature to that of solidification, this contraction being usually made up by gravity feed from the gates. (2) Solidification s., the contraction in volume when the metal (or alloy) passes from the liquid to the solid state at the freezing point, which, however, may not be at one temperature, but may extend over a range. The lost volume must be made up by supplying further liquid metal from runners and risers, if the formation of shrinkage cavities (q.v.) is to be avoided. (3) Solid s., the contraction in length on cooling from the freezing point to normal temperature, represented by the pattern-maker's usual allowance for contraction after solidification. (4) In Powder Metallurgy, s. denotes the decrease in volume of a compact which may occur during sintering.

Shrinkage Cavity (Draw or Shrink). An internal cavity produced during solidification of a casting, due to the contraction in volume occurring on solidification and the lack of further liquid metal to occupy the resulting space. S.c. thus usually occur in the interior of heavy sections, or at the junction of thin and thick sections, when the prior solidification of the thinner prevents the supply of liquid metal to the thicker portion. S.c. differ from blowholes in having usually a much more irregular surface, showing the dendritic solidification of the metal. A minor s. effect is known as incipient s. (q.v.). *See Sink.*

Siemens or Siemens-Martin Furnace. *See Open-Hearth P.*

Silicon. Si. El. A.W. 28.06 ; At. No. 14. Non-metal, resembling carbon in chemical properties and existing in three forms, amorphous, graphitoidal and crystalline. Occurs in *silica*, SiO_2 , varieties of which are sand, quartz, flint, etc. ; while silica is also a constituent of many rocks. Extracted by the reduction of silica in the electric furnace. S. is an important constituent in steel, in which it may occur either in solid solution as iron silicide, FeSi , which can dissolve to the extent of some 7 per cent. in the ferrite ; or as oxide, SiO_2 , a constituent of the silicate inclusions, where it

Si

arises from the use of ferro-silicon as a deoxidizer. Its presence as silicate is prejudicial to mechanical quality. When present in steel to the extent of 0.10 per cent., or so, its most important effect is to depress the temperature at which gases are liberated from molten steel below that at which solidification occurs, giving steel which is more solid, known as killed steel (q.v.). Up to some 0.30 per cent., s. has little direct effect on mechanical quality; but higher proportions tend to increase strength and reduce ductility. Still higher proportions are used in high-permeability electrical steels, heat-resisting steels and alloy steels for various other purposes. In cast iron, s. occurs chiefly as the silicide, dissolved in the ferrite, and acts indirectly (by its effect on the carbon) as a softener, promoting graphitization, fluidity and softness; and reducing strength and hardness. The s. must thus be proportional to the mass and section of the castings, as well as the duty, insufficient s. giving rise to hard and brittle castings. S. is *directly* a hardener, as in the high s. acid-resisting irons, which are very hard and brittle. Copper-s. alloys are substitutes for bronzes; while s. is also an important constituent in various aluminium alloys.

Silver. Ag. El. A.W. 107.88; At. No. 47; S.G. 10.5; M. Pt. 960° C. Pure white metal, rather soft, very malleable and ductile; the best known conductor of heat and electricity; tarnishes in the atmosphere, but very resistant to many types of chemical attack. Occurs frequently native; also as *argentite* or *silver glance*, Ag_2S ; *chlorargyrite* or *horn-silver*, AgCl ; *pyrargyrite* or *ruby-silver*, Ag_3SbS_3 , and other minerals. Extracted by several methods, chiefly from lead-zinc-silver ores; and to a much lesser extent from auriferous ores. Fine s. is usually at least 99.9 per cent. pure, while "standard" or "sterling" s., containing 7.5 per cent. of copper, is the alloy hall-marked in the British Empire and the U.S.A., and used for coinage and jewellery. Pure s. is used in the construction of chemical plant employed in contact with acetic acid, dilute hydrochloric acid, chlorine, strong alkalies, etc.; in electroplating, as a catalyst in the oxidation of ethyl alcohol; in aero-engine bearings, etc. S.-plated copper, phosphor bronze and brass electrical contacts show considerable advantages over pure copper, the overheating of which produces oxides with relatively high specific resistances. S. is not so affected, there being no stable oxide within the normal working temperature of electrical apparatus. Any surface deterioration is due to the formation of sulphide, which, although having a high specific resistance, is produced very slowly at normal temperatures. S. is also used in brazing alloys, as a substitute for tin in solder, in aluminium alloys for the manufacture of scientific instruments, to harden commutator copper, and in various other alloys

Sin

cobalt with the carbide. To the product is added a proportion of paraffin wax dissolved in a suitable solvent, and the mixed powder is pressed in a hydraulic press into rectangular bars which are just strong enough to be handled. The bars are then sintered in two stages, pre-sintering in tube furnaces in hydrogen at about 800° C., the product being then strong enough to be cut to shape with carborundum dies, or by turning, drilling or filing. The final sintering is effected in electrically-heated carbon tubes at 1400°–1475° C. in an atmosphere of pure dry hydrogen. The sintered tips are finally brazed to the tool holder, and ground to size and polished. Among such alloys are Widia, Carboloy, Elmarid, Ardoloy, Cutanit, Tecometal, etc.

Sintering. In Powder Metallurgy, the bonding together of the separate metal particles in a powder compact, the process being usually assisted by increase of pressure and temperature. In general, the term applies only if the temperature at which the bonding occurs is below the melting point of any of the constituents. Cohesion is effected by interlocking and by actual union of the particles by the action of surface forces. S. is used in the production of hard metal cutting tools, porous bronze bearings, oil pump gears, permanent magnets, etc.

Sintering, Continuous. In Powder Metallurgy, pre-s., or s., in such a manner that the objects are advanced through the furnace at a fixed rate by manual or mechanical means (A.S.M. Defn.).

Sintering Furnace. In Powder Metallurgy, a f. used to heat metal powders or compacts during the pre-s. or s. operations. The heating and subsequent cooling may be carried out in a controlled, inert or reducing atmosphere; or in a vacuum (A.S.M. Defn.).

Sizing (or Coining). In Powder Metallurgy, a final pressing on a sintered compact, to get desired size or physical properties (A.S.M. Defn.).

Skelp. A plate of steel or wrought iron from which pipe or tubing is made. This is done by rolling the skelp up longitudinally into shape and welding or riveting the edges together (A.S.M. Defn.).

Skiagraph (or Skiagram). See Radiograph.

Slab. A rectangular piece of steel which is to be rolled down into plates. It may be considered as very thick semi-finished plate (A.S.M. Defn.).

Slab Pile. In the manufacture of wrought iron, a p. built up wholly of flat bars of iron, all bars running the full length of the p. (A.S.T.M. Stds., A81—33.)

Slag. Non-metallic material, frequently complex silicates and sulphides, produced, with the reduced metal, during a smelting operation; in a further refining process; in re-melting metal, or in the purification of molten metal before casting. S. may arise from the earthy impurities in the ore, from the furnace lining or from additions made in a process. By reason of its lower specific gravity and melting point, s. separates to a considerable extent from molten metal. The fact that reduced wrought iron is not liquefied, but produced in a pasty condition, renders its slag content much higher than that of steel. Incomplete removal of s. from metal, *e.g.*, steel, gives rise to non-metallic inclusions, often found in small quantities in commercial alloys. S. inclusions due to reactions taking place in the molten and solidifying metal may be termed *native* s. particles; those merely mechanically admixed, and reaction products respectively between these and the native s., being termed *foreign* s. particles. *See also* Inclusions, Fibre, Wrought Iron, etc.

Slag Shortness. Brittleness due to the presence of slag in the solid material.

Slip Bands (or Slip Lines). A series of approximately parallel dark bands or lines running across a crystal, and shown on microscopic examination of a piece of ductile metal which has had one face prepared for such examination, and has then been plastically strained. With progressive deformation, more and more lines continue to appear between the previous ones, so that the lines become more closely spaced. They denote the crystal planes (known as slip-planes) along which, on the elastic limit being exceeded, sliding or slip occurs by the movement of one layer of the crystal in relation to another. The existence of three series of slip planes will permit of distortion of any kind. In the cubic system, there are usually four series, parallel with the octahedral faces, but those parallel with cubic faces sometimes occur. S.b. usually change their direction at grain boundaries, by reason of the varying orientation from grain to grain.

Slip Crack (or Pressing Crack). In Powder Metallurgy, a rupture in the pressed compact caused by the mass slippage of a part of the compact (A.S.M. Defn.).

Slip Planes. *See* Slip Bands.

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Smelting. The chemical reduction of a metal from its ore by a process usually involving fusion, so that the earthy and other impurities, separating as lighter and more fusible slags, can readily be removed from the reduced metal. An example is the reduction of iron ore (iron oxide) by coke in the blast furnace to produce pig iron (q.v.). S. may also involve preliminary treatment of the ore, as by calcination and further refining processes, before the metal is fit for a particular industrial use.

Smithing. The shaping of a piece of metal by the hammer, usually when hot, and including the process of forging, flattening, straightening and welding.

Snowflakes. *See* **Flakes.**

Soaking. The process of holding a steel ingot or other part at a given temperature until the material has become uniformly heated throughout to that temperature. S. is usually a preparation for some further operation, *e.g.*, forging or rolling. Heating up prior to s. should be gradual, particularly, for example, with ingots of high-speed steel. These are heated in a furnace of lower temperature for s., and then transferred to a hotter one for final heating before forging.

Sodium. Na. El. A.W. 22.997; At. No. 11; S.G. 0.97; M. Pt. 97.5° C. Soft silvery-white lustrous alkali metal, rapidly tarnishing in air, owing to the formation of a film of oxide; reacts violently with water to form the hydroxide, with the evolution of hydrogen; a good conductor of electricity. Occurs as *rock-salt*, NaCl; *Chile saltpetre*, NaNO₃; *borax*, Na₂B₄O₇·H₂O, and in many other minerals, sea water, etc. Extracted by the electrolysis of fused caustic soda. Used chiefly for chemical purposes, particularly in the manufacture of tetra-ethyl lead for anti-knock purposes, where the lead-sodium alloy is treated with ethyl chloride or ethylene bromide; but it has also a limited application in s. vapour lamps, and as a centring in the copper wire of electric cables and the shanks of valves for internal combustion engines. A s.-potassium alloy, liquid at ordinary temperatures, is used for thermometers at temperatures above the boiling point of mercury (357° C.). S. is also used in the modification (q.v.) of silicon-aluminium alloys; and, in small proportion, as a hardener in lead-base bearing alloys (*e.g.*, Bahnmetall, Satco).

Sol. *See* **Colloid.**

Soldering. The process of joining the surfaces of similar or dissimilar metals by the insertion of a tin-lead alloy (or suitable alternative) of lower melting point, the process being usually carried out within a temperature range of 183° – 310° C. The surfaces to be joined must be free from oxide films, as is ensured by the use of a suitable flux (usually zinc chloride); while the joint strength is not more than about 5 tons per sq. in. Zinc chloride and many other fluxes are corrosive, and may unduly affect parts of small section, such as wire, while also giving rise to a residue which is electrically conductive. For electrical joints, therefore, resin is used, often—for ease of application—dissolved in alcohol. Since resin is a protective and not an active flux, the surfaces must be cleaned mechanically before application. A wide diversity of metals and alloys can be successfully soldered, many special solders, with their appropriate fluxes, being employed. S. with tin-lead and other low m. pt. alloys is often termed soft s., in distinction to hard s., using brazing alloys at much higher temperatures, this process being preferably described, however, as brazing (q.v.).

Solders. (1) Originally, and as still usually understood, tin-lead alloys used in soldering (q.v.), and varying in composition with the duty. Thus, Tinman's Fine S. must have a low m. pt., and approximates in composition to the tin-lead eutectic alloy (containing 37.07 per cent. of lead—m. pt. 183° C.), the 2 tin : 1 lead alloy being commonly used. Plumber's S. must have a long pasty range, to facilitate "wiping" of the joint. With the 2 lead : 1 tin alloy, there is a solidification range of nearly 70° C., and this alloy is commonly used. Alloys of intermediate composition are also employed; and the more recent need for economy in tin has led to the development of a range of substitute alloys of reduced tin content, some containing silver. The usual fluxes are resin or zinc chloride ("killed spirits"). (2) Solders with many other compositions are used, with the appropriate fluxes, for the jointing of other metals and alloys.

Solid Solution. In a binary or more complex alloy, a homogeneous solid phase which can vary continuously in composition between certain limits without any sudden change in properties. The atoms of a s.s. are disposed in a space lattice of the form characteristic of the solvent metal. In the usual or substitutional s.s., the lattice positions are occupied in a random manner by atoms of the solvent and solute metals, in proportions demanded by the composition of the alloy. In some alloys, this random or disordered arrangement is found only above a particular critical temperature, varying with the alloy. Below this temperature, the respective atoms of the solvent and solute arrange themselves in a particular

Sol

or ordered pattern, such alloys of course necessarily showing a simple ratio of the one kind of atoms to the other. The resulting pattern, being superimposed upon the initial lattice, is known as a *superlattice*. The varying arrangement of atoms in the two states, which do not represent different phases, is associated with considerable differences in properties, the disordered state being associated with softness and ductility; and the ordered state with hardness and brittleness. In the less usual interstitial s.s., the atoms of the solute metal are much smaller than those of the solvent, and can therefore occupy positions between them.

Solidification Range (or Crystallization Interval). The temperature *r.* through which alloys may gradually solidify. Above this *r.*, the alloys are completely liquid; below it, completely solid. In the *r.*, they are partly liquid and partly solid.

Solidifying Point. *See* Freezing Point.

Solids. Substances which undergo permanent deformation only when subjected to shearing stress in excess of some finite value characteristic of the substance. *Plastic solids* are those substances which do not deform under a shearing stress until the stress attains a critical value (yield stress), when the solids deform so readily or so quickly that, except for inertia effects, the stress never exceeds the yield stress. *Elastic solids* are those substances in which, for all values of the shearing stress below the rupture stress (shear strength), the strain is fully determined by the stress, regardless of whether the stress is increasing or decreasing. Most solids exhibit combinations of properties. Metals, for example, are mainly elastic-plastic, while some petroleum residues, waxes and similar materials are plastic-viscous. Some materials exhibit even more complex deformation, for example, rubber compounds. (A.S.T.M. Stds., E24—37T.)

Solidus, Solidus Curve or Melting-Point Curve. In a constitutional or equilibrium diagram, the lines indicating the temperatures below which all alloys in the system are completely solid. *Cf.* Liquidus.

Solubility Curve. A *c.* representing the relation between temperature (plotted vertically) and percentage composition of the mixture or alloy (plotted horizontally), showing the mutual *s.* of two liquids or solids in each other.

Solute. Of two mutually soluble metals, that which is in deficiency is known as the *s.* *Cf.* Solvent.

Solution. A homogeneous mixture of either a gas, a liquid or a solid, with a liquid, termed the solvent. Within the limits of existence of the s., and the limiting compositions within which it can remain homogeneous, the composition of the mixture can undergo continuous variation. *See also Solid Solution.*

Solution Heat Treatment. A treatment in which an alloy is heated to a suitable temperature and held at this temperature for a sufficient length of time to allow a desired constituent to enter into solid solution, followed by rapid cooling to hold the constituent in solution. The material is left in a state of unstable equilibrium, and if reheated, may undergo Precipitation Hardening. (Prop. Std. Defn., A.S.T.M., 1942.)

Solution Temperature, Critical. *See Critical Solution Temperature.*

Solution Treatment. The process of heating an alloy to such a temperature as will induce the complete solubility of certain constituents (which are less soluble at lower temperatures), followed by quenching from the higher temperature so as to maintain the super-saturated solid solution in the cold. S.t., which is applied to many aluminium and magnesium alloys, may be the state in which the alloy is put into service, being in general that in which it is best fitted to resist corrosion attack. Alternatively, the alloy may be further subjected to age-hardening (q.v.). *Cf. Homogenizing.*

Solutions, Conjugate. *See Conjugate Solutions.*

Solvent. Of two mutually soluble metals, that which is in excess is known as the s. *Cf. Solute.*

Sonims. Solid non-metallic inclusions in metal (A.S.M. Defn.).

Sorbite. A minutely granular aggregate of ferrite and cementite obtained by the tempering of martensite at a temperature still higher than that giving rise to troostite. Further and higher tempering causes globular carbides to appear clearly. S. can be obtained by quenching while cooling through the A_{r1} point, and also by tempering quenched steels to 600° C. It is intermediate in properties between troostite and pearlite, being softer and more ductile than troostite; but stronger, harder and less ductile than pearlite. S. is thus a valuable constituent in certain constructional steels, and, in the manufacture of rails, its production is sometimes ensured by special treatment.

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Sorbitic Pearlite. A minutely lamellar constituent obtained in the cooling of steel when the cooling rate is slower than that giving rise to troostite, but more rapid than that giving rise to the usual and obviously lamellar p. It is produced by the air-cooling of carbon steels in small sizes, or the oil-quenching of larger sizes, being found in the interior of such bars. The only difference between s.p. and true p. is that the lamellar structure is much finer in the first, giving rise to a correspondingly greater hardness. Coarse p. shows a Brinell hardness value of about 210 and s.p. one of about 420.

Sound Decay. *See Aphonia.*

Sow. The iron cast in the main sand channel into which the stream of molten iron from the blast furnace is led, that from the lateral channels being run into "pigs".

Space Lattice. *See Lattice.*

Spalling. (1) The cracking and flaking of small particles of metal from the surface (A.S.M. Defn.). (2) The splintering or cracking of a refractory material, usually caused by varying expansion due to unequal heating, the separation of fragments exposing fresh surfaces.

Spark Testing. A study of the types and colours of s. produced from different kinds of steel when an abrasive wheel, revolving at high speed, is pressed against them. The s. consist of streaks and spurts, the last denoting the occurrence of minute explosions, seen as small stars, due either to the formation of gaseous products of combustion or the vaporizing of the metal. The streaks vary in length and colour, and the spurts in type and quantity. Carbon tool steel shows white streaks with many fine spurts, whose branches "repeat" or explode again, and sometimes again. High-speed steel shows red streaks with a very few forked spurts. Other elements, as chromium, molybdenum, silicon and vanadium, also impart particular characteristics to these s. The test affords a means of classifying steels into groups of similar composition, but cannot be successfully used as a means of identifying an unknown steel.

Specific Damping Capacity. *See Damping Capacity.*

Specific Gravity. Of a solid or liquid, the ratio of the mass to the mass of an equal volume of water at a standard temperature, usually 4° C. (39.2° F.); although one of 60° F. is sometimes employed. S.g. is thus expressed as a pure number; density as mass per unit volume. The true s.g. of a solid refers only to the solid matter of

the material. If it contains pores or cavities, the *apparent* s.g. is determined, this value being always lower than the true one. If the material is a gas, air at 0°C . and 760 mm. barometric pressure is the standard.

Specific Heat of a substance is the ratio of its thermal capacity to that of water; usually, of water at 15°C . The number of gram-calories to raise the temperature of water at 15°C . by 1°C . is 1.000; and the s.h. of a substance may thus be regarded as the number of gram-calories required to raise the temperature of 1 gm. of the substance through 1°C . For the same substance, the s.h. varies with the previous treatment and with temperature.

Specific Surface. In Powder Metallurgy, the surface area of one grain of powder, usually expressed in sq. cm. (A.S.M. Defn.).

Specific Tenacity. A value, suggested by Rosenhain, representing the ratio of tensile strength to density, and enabling one to obtain a fair comparison of the strengths of materials differing widely in density. The s.t. of widely different materials are only really comparable, however, if they have similar ductilities.

Specific Volume. The reciprocal of the density, being the volume, at a specified temperature and pressure, occupied by unit weight of a substance.

Specification. The pre-determined requirements as to methods of manufacture, composition, minimum or maximum mechanical test values, corrosion resistance or other standards to which a material must conform before it can be accepted for service.

Spectrograph. (1) An instrument which makes a photographic record of a spectrum (q.v.). It closely resembles a spectroscope (q.v.), the observing telescope of this being merely replaced by a camera having a suitable object glass. (2) The spectrum photograph obtained by means of such an instrument.

Spectroscope. An instrument for the visual observation of a spectrum (q.v.). Light from the source under examination enters the instrument through a narrow slit, situated at the principal focus of a lens, the parallel rays of light, of mixed colour, then falling on an arrangement of prisms; where, for example, the dispersion of a very wide-angled dense flint-glass prism is partly corrected by crown-glass prisms, when the deviation of the mean rays of the spectrum is completely corrected, and that of the extreme rays only partially so. On passing through another lens, they are focused at different

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points, so as to form a spectrum. The second lens and the eyepiece are generally combined in the form of a telescope, which can be rotated about the centre of the prismatic arrangement, so that different parts of the spectrum can be observed. *See also Spectrograph.*

Spectrum. The effect obtained when radiation from a self-luminous source (*emission s.*) is separated by refraction into its component radiations; as may be accomplished by means of a spectroscope (q.v.) or diffraction grating. Thus, white light may be split up into a range of colours, merging imperceptibly into each other, from red (least refracted) to violet (most refracted). This is a *continuous s.*, although not necessarily equally bright throughout, and is typical of incandescent solids or liquids. Luminous gases give *discontinuous spectra*, consisting of bright lines or bands of different colours on a dark background (*line* or *band s.*, respectively). These lines or bands represent a succession of images of the slit, either separated as lines, an effect characteristic of atoms; or crowded together as bands, an effect characteristic of molecules. These bands can be separated only with difficulty. A succession of bands sharply defined at one edge, the "head" of the band, and diffused at the other, are termed *flutings*. No two substances show the same s. That of every element is typical and serves to identify it, this principle being utilized in *s. analysis*. When light from a source giving rise to a continuous s. is passed through an absorbing medium, parts of the s. disappear, the issuing ray now showing, on a coloured background, dark lines or bands corresponding with the radiation not transmitted, and in positions characteristic of the absorbing medium. This is an *absorption s.*, which generally differs from the emission s. of the same substance.

Spelter. Commercial zinc, containing lead and other impurities, cast from the molten metal into slabs, plates or ingots. The term does not include zinc dust.

Spherical. In Powder Metallurgy, metal powder particles of spherical shape which may be either solid or porous (A.S.M. Defn.).

Spheroidal Cementite (Spheroidized, Globular or Divorced C., or Spheroidite). The product of long annealing of unhardened steel (spheroidizing anneal) near but below its transformation range, whereby the carbide lamellæ in pearlite areas ball up into small globules in the ferrite matrix. The same structure is achieved by long, high tempering of hardened steel. *Note.*—The term "spheroidized pearlite" should be avoided, when the structure is undoubtedly the result of spheroidizing anneal of a pearlitic steel.

The term "spheroidite" has been proposed (A.S.M. Defn.). (*N.B.* It should be noted that the spheroidizing process is facilitated if the steel has previously been cold-worked, the speed of the reaction increasing with the degree of cold-working.) *See also Divorced Pearlite.*

Spheroidizing (or Spheroidization). The production of a globular condition of the cementite obtained by prolonged annealing of steels at a temperature near to, but generally slightly below, the A_{r1} or pearlite change point, at about 700°C . By the effect of surface tension, the cementite coalesces or "balls-up" into small globules regularly distributed through the soft ferrite. The steel is then in its softest state, and the cementite dissolves most rapidly when heated to the quenching temperature. The process of s. is promoted by previous cold working. With small samples of high-carbon steel, s. is more readily accomplished by prolonged heating at temperatures alternately slightly above and slightly below the change point. The term may also be applied to a similar effect involving the coalescence of the particles of a dispersed phase in other alloys. *See also Divorced Pearlite.*

Spiegel (Spiegeleisen or Spiegel-Iron). Manganiferous white cast iron, usually containing 4.5–5.5 per cent. of carbon and 15–30 per cent. of manganese; used in the manufacture of steel by the Bessemer process.

Spinning. A method of shaping shallow metal articles in a lathe. The circular blank, which may be cut from sheet, is greased with tallow and held up against the spinning chuck by means of a pad on the tailstock. By pressing a suitably-shaped tool, which is supported on the hand-rest, against its periphery, the circle is gradually formed or "spun" over the chuck, the wall-thickness of the article being reduced as required, according to how the tool is used. Complete shaping may require several stages, with intermediate annealing between each. *Cf. Deep Drawing.*

Spitting (or Sprouting). The explosive liberation of dissolved gas from a metal during the process of solidification, due to an abrupt diminution in gas solubility with change of state. A characteristic example is the s. of silver containing dissolved oxygen.

"Split" Transformation of Austenite. An effect obtained when the rate of cooling is less than the critical cooling rate (q.v.), the a. transforming, partly within the higher temperature range (about 550°C .) to pearlite; and partly within the lower temperature range

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(below 150° C.) to martensite, the proportion of each formed depending upon the time the steel is kept in the high-temperature range, with all the pearlite forming that time will permit. A s.t. is always found in the quenching of large parts, in which the exterior portions are martensitic, and the interior pearlitic; intermediate regions being partly martensitic and partly pearlitic, by reason of the s.t. at intermediate cooling rates prevailing there. *See also S-Curves.*

Sponginess. *See Porosity.*

Spongy. (1) *See Porosity.* (2) In Powder Metallurgy, a porous condition in metal powder particles usually observed in reduced oxides (A.S.M. Defn.).

Spontaneous Annealing. *See Self-A.*

Sprills. Metal powder particles of cylindrical form, not much larger than their diameter (A.S.M. Defn.).

Sprouting. *See Spitting.*

Stabilization. (1) The retarding or prevention of a particular reaction by the addition of a stabilizer, or "negative catalyst". (2) A stabilizing heat treatment, to relieve internal stresses (A.S.T.M. Stds. Bro6—40.)

Stabilizers (or Carbide Stabilizers). (1) Additional alloying elements added to 18 : 8 chromium-nickel stainless steels, to prevent the intercrystalline corrosion effect known as weld decay (q.v.). The two s. in most common use are columbium and titanium, each of which combines with carbon preferentially to chromium. They should be added to the extent of ten times the carbon content for columbium and six times this for titanium. For the latter, a stabilizing heat treatment is usually given in addition, the alloy being heated in the 850°–900° C. temperature range, when all the excess carbon is precipitated as titanium carbide, and no further change can occur on exposure to a lower temperature. With columbium, the additional heat treatment is unnecessary. Other metals, as molybdenum, tungsten and vanadium, are also used as s. (2) The term has also a more general application, *e.g.*, for alloy elements which tend to stabilize ferrite (*e.g.*, chromium, tungsten, molybdenum, etc.) or austenite (*e.g.*, manganese, nickel, cobalt, etc.).

Stable Equilibrium. *See E. and Metastable E.*

Stainless "Iron". (1) A low-carbon s. steel (q.v.), with a chromium content of 12-16 per cent., but a carbon content as low as possible, usually about 0.10 per cent. S.i. is thus softer than s.s., and can be more readily worked and welded. The corrosion-resistance of s.i. is superior, but it is mechanically weaker than s. steel. (2) An alloy with a higher chromium content (16-30 per cent.), and about 0.1 per cent. of carbon, when the composition falls outside the γ -loop (q.v.), and the i. becomes permanently ferritic. Such i. has a high corrosion-resistance and is readily worked, but has a low notch-value and does not respond to the usual heat treatment. Coarse-grained i. can be refined only by cold work followed by heat treatment, causing recrystallization. (3) A high-chromium i. (e.g., 18 per cent., with 0.1-0.2 per cent. of carbon) to which 2 per cent. of nickel has been added, when the alloy becomes once more responsive to the usual hardening and tempering treatment. The improved mechanical quality, combined with a high corrosion-resistance, makes such an alloy very suitable for many duties, as valves and rods for steam and hydraulic service, pump shafts for use with acid mine waters, etc.

Stainless Steel. Alloy s. comparatively unaffected by atmospheric attack, and much more resistant than ordinary s. to many corrosive agents. There are two main classes: (1) Pearlitic s.s., containing usually 12-16 per cent. of chromium and 0.2-0.4 per cent. of carbon. The carbon content varies with the duty, e.g., about 0.23 per cent. for turbine blades, 0.3 per cent. for cutlery and 0.4 per cent. for springs. Such s. is more resistant in the heat-treated state. A suitable treatment for turbine blades is: Oil-harden at 970° C.; water-quench at 710° C. A similar alloy with lower carbon content is the so-called "Stainless Iron" (q.v.). (2) Austenitic s.s., containing usually not less than 18 per cent. of chromium and 8 per cent. of nickel, with, frequently, additional elements to impart special qualities. Such s. are decidedly more corrosion-resistant than the pearlitic s.s. They are soft and malleable, but rapidly work-harden, and are also subject to "weld-decay" (q.v.), an effect which can be prevented by the addition of stabilizers. Austenitic s.s. are softened by heating to 1100°-1200° C., followed by cooling in air and de-scaling. They do not respond to the usual heat treatment. There is a further variety of austenitic s.s., containing about 12 per cent. each of chromium and nickel. These are softer, and can therefore be shaped, as for ornamental goods, more readily.

Stamping. See Drop-Forging.

Stationary States. See Quantum Numbers, etc.

Ste

Stead's Brittleness. A type of b. shown by low-carbon steels which have been strained to a critical degree, and then annealed for a period at temperatures between 500° and 750° C., when there is a considerable increase in ferrite grain size and a corresponding increase in b., shown, for example, by the reduction in notch value.

Steel. A malleable iron-carbon alloy, in which the carbon—usually not in excess of 1.7 per cent.—is wholly in the combined state; while the content of manganese is usually substantial.

"Stickers". Sheets which have stuck together in annealing, due to too high an annealing temperature, the undue height of the pile, the unevenness of the floor of the chamber (so as to concentrate pressure locally), etc.

Stiffness. See **Rigidity.**

Straight. The ordinary type; e.g., s. carbon steel, as distinct from alloy steel.

Strain (or Deformation). A change in form produced in a non-rigid body by the action of an external force or load. S. may be *elastic*, so that the body returns to its original dimensions when the force is removed; or *plastic*, when the body remains permanently deformed after removal of the load. S. in tension or compression is measured by the change per unit of length along the dimension under consideration, a change which is positive in tension and negative in compression. Shear s. is measured at right angles to the dimension under consideration. Torsional s., which also involves shear s., is measured by the angular degrees of twist.

Strain-Age-Embrittlement. See **Strain-Age-Hardening.**

Strain-Age-Hardening. An effect shown in low-carbon steels which have been cold-rolled (particularly with elongation values between 1.5 and 10 per cent.) and then allowed to remain for a period at atmospheric temperature. Steel so treated shows increased yield point and ultimate stress values, with reduction in ductility and toughness values (s.-a.-embrittlement). Coarse-grained steels show greater s.-a.-h. than fine-grained ones; and the Izod value may sometimes be reduced to a very low figure. In the absence of carbon, iron does not show s.-a.-h., and one type of s.-a.-h. is undoubtedly due to the presence of carbon. The exact mechanism is doubtful, but the h. effect is probably due to the fact that carbon which is dissolved to a very small extent in ferrite at the ordinary temperature tends to be "re-precipitated", or leads to a

distortion of the crystal space lattice, after straining and ageing. Whether this effect is enhanced by an increased solid solubility of iron carbide in ferrite during straining is uncertain. The extent of s.-a.-h. is increased by the presence of elements (as copper and nickel) which show little or no tendency to combine with the carbon present in steel ; and is diminished by the presence of those (as molybdenum, manganese, chromium, vanadium, columbium and titanium) which tend to form carbides more stable than iron carbide. The addition of sufficient of one of the last group of alloy constituents prevents any s.-a.-h.

Strain-Ageing. A change in the mechanical quality of cold-worked material, occurring spontaneously with lapse of time at ordinary temperatures, and more rapidly at higher temperatures. *See Ageing, Age-Hardening, Strain-Age-Hardening, etc.*

Strain-Hardening. *See Work-Hardening.*

Strength. The resistance to yielding or breaking which a material opposes to a force acting upon it. S. is not a definite property of a material, but one the magnitude of which varies according to the method used in determining it. Hardness (q.v.) can be regarded as one kind of s.

Stress. The intensity (measured as force, or load, per unit area—lb. per sq. in., kilos per sq. mm., etc.) of an internally distributed force resisting the deformation of a body, thus representing the internal mechanical reaction of the material to deformation. A s., which is usually calculated on the basis of the original cross-section of the body, may be uniform over the whole section, or may vary from one position to another. S. always occur in pairs, and may be tensile (the forces acting away from each other), compressive (towards one another) or shearing (parallel with one another). A pure bending s. involves the combination of a tensile and a compressive s. ; but other types of bending s. involve shearing. Torsion involves shearing. No matter how complex the distribution of s. in a body, there are always three mutually perpendicular planes ("principal planes") on which the s. ("principal s.") are entirely normal. Unit s., or intensity of s., is the load per unit area of surface.

" Stress-Raiser ". Any cause giving rise to a local intensification of the stress supported by the article. Among such are re-entrant angles, insufficient fillets, tool-marks, key-ways, oil channels, slag inclusions, mechanical defects, the graphite inclusions in cast iron,

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corrosion pits, etc. All of these serve frequently as loci for the propagation of fatigue failures.

Stress Relief Annealing. Annealing for the purpose of removing residual internal stresses (q.v.). *See Stress Relieving.*

Stress Relieving. A process to reduce internal residual stresses in a metal object by heating the object to a temperature below the transformation range and holding for a proper time at that temperature. This treatment may be applied to relieve stresses induced by casting, quenching, normalizing, machining, cold working, or welding. (Prop. Std. Defn., A.S.T.M., 1942.)

Stress-Strain Diagram. A diagram, applying usually to tensile loading, plotted with unit stresses as ordinates and unit strains as abscissæ. It differs from a load-extension diagram (q.v.) in that both stresses and strains are actual and not nominal, and the load-extension diagram can be regarded as an adequate substitute for it only in that portion of the curve between the origin and the elastic limit. Actual stresses can be determined only by the use of an autographically-recording extensometer. Again, in the load-extension diagram, the amount of strain varies along the gauge length, and the extension at any stage in the test divided by the original gauge length represents only the *average* unit strain. For any given length which is infinitely short, the actual unit strain must be equal to the reduction of area divided by the original area at the same place, if the density of the material remains constant during the test.

Stretch Modulus. *See Elastic M.*

Stretcher Strains or Worms (Lüders Lines, Hartmann Lines or Piobert Effect). Worm-like markings due to differences of surface level, often shown on the surface of annealed mild steel sheet or strip having a pronounced yield point and subjected to stamping or drawing, in which the material is permanently deformed. These relief markings are due to the deformation occurring, not evenly, but locally, so that strained and comparatively unstrained regions alternate. S.s. are found with deformations up to some 4 or 5 per cent. elongation, after which they disappear. They can be prevented by slightly cold-working the steel, by a pinch or light roll pass, before drawing or stamping. The pronounced yield point is thus eliminated; this effect, however, vanishing after about one day, so that the operation must be completed within this period. The s.-s. effect is also seen in the defects known as kinking, fluting and panelling.

Strontium. Sr. El. A.W. 87.63; At. No. 38; S.G. 2.54; M. Pt. 771° C. Yellowish-white "alkaline earth" metal, resembling calcium in its properties; oxidizing in the air and decomposing water. Occurs as *celestite* or *celestine*, SrSO_4 ; and *strontianite*, SrCO_3 . Obtained either from the oxide by the thermit process, followed by re-distillation at 1000° C.; or by the electrolysis of the fused chloride. Used as a deoxidizer in copper, bronzes, etc.; as a deoxidizer and desulphurizer in the open-hearth steel process; as an alloy in lead for storage batteries, to increase hardness and durability, etc.

Sub-Atom. A constituent of the atom (q.v.), such as a proton, electron, neutron, etc.

Sub-Boundary Structure. See *Veining*.

Sub-Critical Annealing. The a. of steel at temperatures just below A_{c1} , in order to obtain maximum softness without recrystallization. Temperatures usually employed are 670°–720° C.

Sulphur. S. El. A.W. 32.06; At. No. 16. Non-metal, usually a pale yellow, brittle, fusible and inflammable solid (rhombic s.); occurring also as prismatic s., and in two amorphous forms, plastic s. and white amorphous s. S. is an impurity or sometimes an addition in various alloys, *e.g.*: (1) In steel, an undesirable impurity, usually below 0.06 per cent. In the absence of manganese, s. causes red shortness, through the segregation of iron sulphide (m. pt. 1193° C., well below that of iron) as brittle films at the crystal boundaries. When enough manganese is present, this effect is prevented, by reason of the production of sufficient manganese sulphide, with a m. pt. (1620° C.) higher than that of iron. The mixture of FeS and MnS solidifies while the steel is still liquid, red shortness being thus avoided. Higher proportions of s., up to some 0.30 per cent., are used in some free-cutting steels, machinability being promoted by the presence of the manganese sulphide inclusions, without prejudice to mechanical quality. (2) In cast iron, s. opposes the effect of silicon, and reduces graphitization. An excess may give rise to iron which is more sluggish, with higher shrinkage, more unsound and harder. In Malleable Cast Iron, s. over 0.10 per cent. renders the material less amenable to the annealing operation. S. may be removed from molten iron by desulphurization with sodium carbonate, followed by the addition of limestone to thicken the very fluid slag, which is then skimmed off. (3) In Monel R, s. is a free-machining addition.

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Sulphur Printing. A macrographic method of determining the relative distribution of sulphur (in the form of dispersed sulphides of iron and manganese) in steel. On the clean smooth surface of the steel is pressed a sheet of photographic bromide paper, moistened with dilute sulphuric acid (3 per cent.); the sulphuretted hydrogen gas thus liberated giving a dark brown stain of silver sulphide (Ag_2S) on the paper. After a suitable period, the paper is peeled off, fixed in "hypo", and washed and dried as usual. Since segregation of sulphur is usually associated with that of other elements, s.p. is a useful guide in this respect. It also indicates the flow lines of forging, or other mechanical process.

Superconductivity. The sudden disappearance of electrical resistance at a particular temperature. This phenomenon, for which there is at present no satisfactory explanation, is found with pure metals, alloys and compounds, at very low temperatures, generally below 10°K .

Supercooling. See Superfusion.

Superfines. In Powder Metallurgy, the portion of a powder sample which is less than 10 microns in size (A.S.M. Defn.).

Superfinishing. The removal, by means of very fine, fixed, abrasive grains, of the rough "fragmented" material left on the surface of a metal or alloy by the previous grinding operation. In addition to the obtaining of a surface of high finish, the object of the process is, frequently, to obtain dimensional accuracy in the article.

Superfusion (Surfusion, Supercooling or Undercooling). The cooling of a liquid below its normal freezing point without solidification. S. can be prevented by slow cooling, by stirring, or by the addition of nuclei of the solid material. See also **Metastable Equilibrium**.

Superheating.* In general, the heating of molten metal to a temperature higher than usual. With ordinary or low-alloy cast iron, s. up to temperatures of 1800°C ., followed by pouring at the usual temperature, gives rise to a refinement of the graphite structure—the flakes becoming short and curly instead of long and straight—a decided improvement in mechanical quality resulting. In the production of high-duty cast irons (q.v.), s. is used to remove any existing graphite particles, and may be followed by inoculation, to obtain a controlled production of new graphite centres on cooling.

Superlattice. See Solid Solution.

Supersonics. *See* **Ultrasonics.**

Surface Hardening. A general term covering a number of processes, in which, to improve wear resistance, increased hardness is imparted to the outside of a steel part; while the interior portions retain either much, or—in some processes—all of the ductility and toughness of the untreated steel. Among s.h. processes are case-h., flame-h., induction-h., nitriding, etc. (q.v.).

Surface, Specific. *See* **Specific Surface.**

Surfusion. *See* **Superfusion.**

Sweat Out. (1) In Powder Metallurgy, the low melting constituent of a compact which melts during sintering and subsequently appears on its surface (A.S.M. Defn.). (2) *See* **Liquation.**

Symbol. The letter or letters representing one atom of an element, *e.g.*, V (vanadium), Cu (copper), Fe (iron), etc.

System. (1) A mass of material, which may be solid, liquid or gaseous, or contain all these states; and is made up of one or more completely homogeneous, mechanically separable and spacially distinct portions, each of which is known as a *phase* (q.v.). *See also* **Phase Rule.** (2) The type of regular structure, as cubic or hexagonal (q.v.), shown by a crystalline solid.

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Tantalum. Ta. El. A.W. 180.88; At. No. 73; S.G. 16.6; M. Pt. 2910° C. Iron-grey metal, which can be readily worked, but hardens rather rapidly. Unusually resistant to corrosion. Occurs as *tantalite*, $\text{Fe}(\text{TaO}_3)_2$, often associated with the isomorphous *columbite*, $\text{Fe}(\text{CbO}_3)_2$. Extracted by a complex wet process and finally obtained, as a metallic powder, either by reduction of the oxide, Ta_2O_5 , with sodium or aluminium in a vacuum electric furnace; or by electrolysis of the fused double fluoride of potassium and t. The powder is washed, heated *in vacuo* and hydraulically compressed into bars, which are heat-treated in vacuum furnaces, hammered, re-treated, and then rolled or drawn. T. combines with all the usual gases when hot, and must therefore always be worked in the cold. Used for the absorption of gases in electrical and radio work; in the manufacture of spinnerets used in the making of rayon; in steam heating equipment for contact with acids; in the lining of various chemical equipment; as a substitute for platinum for standard weights, and in jewellery. T. is used as an alloy in sintered carbide tools, high-speed steels, etc.

Tarnishing. The production of a superficial discoloration on metal, with slight roughening of the surface, often the first sign of corrosion attack.

Teeming. Pouring molten steel or iron from the ladle into ingot moulds (A.S.M. Defn.).

Tellurium. Te. El. A.W. 127.61; At. No. 52; S.G. 6.25; M. Pt. 452° C. A silver-white non-metal with a metallic lustre, brittle, and a poor conductor of heat and electricity. Occurs to a small extent native, but chiefly as metallic tellurides, e.g., *sylvanite*, $(\text{AgAu})\text{Te}_2$; *black tellurium*, $(\text{Au,Pb})_2(\text{Te,S,Sb})_3$; *hessite*, Ag_2Te ; *tetradymite*, Bi_2Te_3 , etc. Extracted chiefly from the residues of bismuth ores, which are dissolved in hydrochloric acid, t. being precipitated by the addition of sodium sulphite. It is purified by boiling with sodium sulphide and powdered sulphur, and adding sodium sulphite, when the t. is precipitated once more as a dark grey powder, becoming white on fusion. T. added to the zinc electrolyte eliminates cobalt as an impurity. A liquid t. lamp gives a continuous instead of a line spectrum and is a source of artificial sunlight. Plated from fluoride solutions, t. gives a corrosion-resistant coating on various metals. In finely powdered form, t. is used in the compounding of rubber, shortening the time of curing and improving

the resistance of the product. As an alloy addition, t. greatly increases the hardness, toughness, strength and corrosion resistance of lead for domestic supply pipes, cable sheathing, chemical plant, etc. It imparts free-cutting quality to brasses and alloy steels; improves the creep strength of pure tin and has a beneficial effect in tin-base bearing alloys.

Temper. A term often very loosely applied, denoting : (1) The degree of hardness *left in* a tool, as distinct from the actual operation of tempering (q.v.). Such t. may be described as : very mild, mild, medium, full, hard or very hard ; or, alternatively, under the name of the duty, as " chisel t.," " punch t.," etc. (2) The carbon content of the steel, and therefore its hardening capacity. Thus " razor t." may describe steel with a carbon content of 1.4 per cent., " tool t." one with a carbon content of 1.25 per cent., and so on. (3) Merely excellence in a tool, as one " of the finest t.," when resilience is probably intended. T. in this sense involves the operations both of hardening and tempering, a usage which is confusing and should be abandoned. (4) As a verb, the operation of tempering (q.v.).

Temper Brittleness. A quality denoted by a marked reduction in the notched-bar value of certain steels which have been allowed to cool slowly after tempering. Nickel-chromium steels, for example, show this effect markedly on tempering, after a previous oil-hardening, at temperatures of 600° and 650° C., when Izod values of 4-6 may be obtained when some 40-60 ft.-lb. are expected. The measure of susceptibility to t.b. is expressed by the ratio between the Izod value, respectively, when the steel is quenched in a liquid medium from the tempering temperature, and when it is slowly cooled from this temperature. If these values are 60 and 6 ft.-lb., respectively, the susceptibility ratio is 10. A suggested reason for t.b. is the segregation of carbides to the grain boundaries, but the cause is still somewhat obscure. The effect can very largely be minimized by quenching the steel from the tempering temperature, or prevented by the addition to the steel of 0.3-0.5 per cent. of molybdenum.

Temper Carbon. Graphite, in finely-divided form, resulting from the decomposition either of cementite or of high-carbon γ -iron, and obtained on heating iron-base alloys below the melting point. It is chemically identical with the graphite produced in the cooling of cast iron. In the production of blackheart malleable cast iron, it results from the decomposition of cementite by annealing white cast iron for a long period at about 750°-850° C., being obtained as aggregates of minute crystals, often surrounded by regions of ferrite, due to the loss of carbon by segregation. The heating of hyper-eutectoid steel,

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particularly that with more than 1 per cent. of carbon, for long periods above its critical range, may also lead to the production of graphite, with most prejudicial effect upon tool quality.

Temper Colours. The colours shown on the surface of polished steel when heated, and due to the formation of thin oxide films, which change in thickness and hue with temperature, and thus afford a good indication of the temperature of the cutting edge. A straw t. corresponds approximately to a temperature of 200°C. , and a blue t. to one of 300°C. When the required temperature is reached, the tool is quenched off in water. Actually, the time factor has a definite effect in tempering, heating longer at a lower temperature giving rise to the same colour, and the equivalent amount of t., produced by a shorter time at a higher temperature. With stainless steels, higher temperatures are required to produce the same t.c.

Temper Hardening. See Age-Hardening.

Temper Rolling. In the production of tinplates, etc., a process (following annealing and immediately preceding cutting the strip into sheet lengths preparatory to white pickling and tinning) in which the annealed coils are subjected, usually in a four-high mill, to a small amount of cold reduction, generally less than 3 per cent., so as to give the dead-soft material further stiffness and t., without undue reduction of the ductility of the material. T.-r. thus eliminates the possibility of stretcher-strain effect (q.v.) in further shaping.

Temperature Stresses. Internal s. (q.v.) set up when the deformation normally caused by change of t. is hindered or prevented, the intensity of the s. being proportional to the degree of normal deformation that is prevented.

Tempering. The re-heating of steel, previously hardened, to a temperature below the range of critical temperature, *i.e.*, below A_{c1} , followed by cooling at any rate desired. T. reduces (or tempers) the extreme degree of strength and hardness obtained on quenching, the reduction in strength and hardness, and the accompanying increase in ductility and toughness, being greater as the t. temperature increases. By variation of t. temperature, a wide range of properties can thus be obtained, intermediate between those of the fully-hardened and fully-softened steels. T. of quenched carbon tool steels at 150° – 200°C. relieves internal stress and reduces liability to cracking, without appreciable diminution of hardness. T. at 200° – 400°C. (a temperature of 300°C. being usually not exceeded for carbon tool steels in practice) gives rise to troostite (q.v.). Further t. of troostite gives rise to sorbite (q.v.), a valuable constituent in

certain structural steels. *See also* Age-Hardening, Secondary Hardening, etc.

Tenacity. The maximum tensile stress which a material is capable of developing; tensile strength. *See also* Specific T.

Tensile Strength. *See* Ultimate Stress.

Tensile Test. A t. in which a suitable bar, having a smaller parallel-sided middle portion—or one of circular section—to ensure that fracture will occur in this part of the bar; and enlarged ends, grooved or screwed so that they may readily be held in the grips of the testing machine applying the load, is broken by a load applied in opposite directions at the two ends. If the cross-sectional area of the parallel or circular portion is made some definite fraction of a square inch, the breaking load in tons per sq. in. is readily calculable. The elongation per cent. and reduction of area per cent. after fracture—measures of the ductility of the material—are determined in the same t.

Tensometer. A miniature portable testing machine, which autographically records load-extension diagrams throughout the test; while elongation and reduction of area per cent. are read off on a gauge without calculation. The test pieces vary in cross-section from $\frac{1}{16}$ to $\frac{1}{4}$ sq. in., and the machine is capable of measuring tensile strength up to a maximum value of 200 tons per sq. in. Tests of Brinell hardness, notched-bar value, transverse strength of brittle materials (*e.g.*, cast iron) and strip tests for sheet materials can also be made on the same machine.

Ternary. Consisting of three components.

Ternary Alloy. An alloy containing three principal elements (A.S.M. Defn.).

Tessellated Stresses. Self-compensated stress systems which develop round such centres as crystals or components of the structure of compound solids. These s. are due to the anisotropy of the single crystals of most materials and the differences between the bulk physical properties of the components of compound solids.

Tetragonal System. A s. of crystallization including all forms referable to three axes at right angles to each other, of which the two lateral axes are equal in length, while the third or vertical axis is either longer or shorter. The fundamental form is the double t. pyramid, or t. bipyramid, in which the length of the vertical axis is

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not an even multiple of that of the lateral axes. Tin in its usual form crystallizes in the t.s. *See also* Lattice.

Thallium. Tl. El. A.W. 204.39; At. No. 81; S.G. 11.85; M. Pt. 303.5° C. Soft greyish-white metal resembling lead; can be scratched with fingernail. Occurs as *crookesite*, (CuTlAg)₂Se; *orbaite*, TlAs₂SbS₈; *lorandite*, TlAsS₃, etc. Extracted from the flue dust from pyrites burners of sulphuric acid works by a wet process, the metal being finally obtained from t. chloride, either by fusing with potassium cyanide and sodium carbonate; or by reduction with zinc and dilute sulphuric acid, followed by melting in an inert gas. T.-lead alloys have higher melting points than either of the component metals, and are used in some special types of electrical fuses. Lead containing 20–65 per cent. of t. is very resistant to corrosion. In lead-base bearing alloys, t. greatly improves the resistance to deformation. A 10 t. : 20 tin : 70 per cent. lead alloy is highly resistant to corrosion, showing, as an anode for the electro-deposition of copper, less than one-fiftieth the corrosion shown by lead. The silver alloy containing 10–22 per cent. t. does not blacken, as does silver, on exposure to the atmosphere.

Thermal Analysis. The determination of transformation temperatures in metals and alloys by means of heating and cooling curves. The usual apparatus consists of an electric resistance furnace capable of constant heating and cooling, a potentiometer for the determination of thermocouple E.M.F. (and therefore of temperature), and a time-recording device, which preferably automatically plots time intervals against the temperature of the specimen. T.a. usually involves the plotting either of inverse-rate or differential heating and cooling curves (q.v.), and—for the complete study of phase relationships—is combined in practice with micro-examination after quenching specimens at appropriate temperatures.

Thermal Expansion (or Expansivity). Increase in dimensions due to increase in temperature. The coefficient of linear e. or expansivity of a solid is the change in length per degree to the length at a standard temperature, generally 0° C. Coefficients per degree F. are five-ninths of those per degree C. Since the coefficient increases with temperature, it is necessary to cite the temperature at which, or the range over which, a particular coefficient holds. The coefficient of superficial e. is approximately twice, and that of cubical e. approximately three times the linear coefficient. The coefficient of volume e. for liquids is the ratio of the change in volume per degree to the volume at 0° C., the value of this coefficient also varying with

temperature. The coefficient of α for gases is almost uniform, about $\frac{1}{273}$ per degree C.

Thermal Lag (or **T. Hysteresis**). The retardation of a structural change by reason of molecular inertia, which tends to maintain an existing phase for a short interval of temperature after passing its true equilibrium temperature, so that the critical temperature denoting a particular transformation is higher on heating and lower on cooling. The amount of this temperature interval, or ΔT , depends upon composition, rate of heating and cooling, etc. With alloy steels, *e.g.*, those containing chromium or manganese, the interval between equivalent transformations on heating and cooling may be very great.

Thermionic Emission. The e . of negatively-charged electrons or positively-charged ions from heated metals. This is utilized in the t. or wireless valve, which consists substantially of a glass vacuum tube, containing (1) a filament which, when electrically heated, emits electrons that flow to (2) a positively-charged plate or anode, the electron flow being regulated by (3) a perforated grid oscillation valve, electrically charged. *See also Cathode Ray, Electron*, etc.

Thermit Process (**Aluminothermic** or **Goldschmidt P.**). A method of reducing metals from their oxides by mixing intimately with aluminium powder in a refractory crucible, and igniting in some suitable manner. The reaction proceeds with great violence and the development of heat sufficient to melt the most refractory metals. The resulting slag is fused alumina, or artificial corundum. Chromium, manganese, titanium and other metals can be so obtained.

Thermocouple. A welded junction of two dissimilar metal or alloy wires, one junction of which is heated or cooled; while, at the same time, the other junction is maintained at a constant known temperature. The thermoelectric difference of potential thus caused is measured by means of a galvanometer or potentiometer, and the hot junction temperature can thus be determined. In practice, the ends of the couple wires which join on to the galvanometer or potentiometer leads constitute the cold junction.

Thermoelectric Power. The thermoelectric power, Q , of two metals is the electromotive force in an electric circuit consisting of the two metals when the junctions between them have a difference in temperature of 1°C . Experimentally, it has been found that the thermoelectric power of two metals is not a constant, but depends on the mean temperature of the junctions. However, over a range of

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temperature from 0° to 100° C., it is usually sufficient to assume that the thermoelectric power is independent of temperature, so that, for this range of temperature :

$$Q = \frac{E}{(t' - t)}$$

where E = the electromotive force developed in the circuit,

• t' = the higher temperature in degrees Centigrade at one junction, and

t = the lower temperature in degrees Centigrade at the other junction.

(A.S.T.M. Std. Method of Test for Thermoelectric Power of Electrical Resistance Alloys, B77—33.)

Thermostat. An apparatus so constructed as to maintain the temperature of a given space constant within certain definite limits by means of an automatic device which cuts off, or reduces, the supply of heat when the required temperature is exceeded, and restores it once more when the temperature falls below that required. The use of a t. is often necessary in metallurgical and allied processes, as in the determination of equilibrium diagrams, where the specimen may require to be heated for an extended period at one temperature ; to maintain a constant temperature of air or water during corrosion tests ; or to maintain a constant temperature : (a) for the cold junction of a thermoelectric pyrometer ; (b) in melting furnaces for tin, type metals and other alloys ; (c) in gas-fired or electrical-resistance furnaces for heat treatment, etc. The methods of actuating the regulating device with change of temperature vary considerably, and may involve the differential expansion of solids, the changes in volume of liquids or gases, the change of electrical resistance of coils, etc. For use at lower temperatures, up to 250° or even 300° C., differential expansion devices are fairly common, various combinations of metals being used. At temperatures over 300° C., there are undue oxidation effects unless more resistant and expensive components are employed. For high-temperature t., the change in resistance of a coil with temperature may similarly be used to control furnace temperatures within very close limits.

Thermostat Metal. A composite material usually in the form of sheet or strip, comprising two or more materials of any appropriate nature, metallic or otherwise, which, by virtue of the differing expansivities of the components, tends to change its curvature when its temperature is changed. (A.S.T.M. Stds., Br06—40.)

Thomas Process. See Bessemer P.

Tin

Thomson Effect. A thermoelectric difference of potential (E.M.F.) set up along a conductor, parts of which are at different temperatures. The amount and direction of the potential difference varies with the material of the conductor. Thus, hot copper is positive to cold copper, and a similar effect is found with antimony, cadmium, zinc and silver. With bismuth, nickel, cobalt, iron, platinum and mercury, the hot metal is negative to the cold. Lead shows neither a positive nor negative T.E. Cf. *Seebeck and Peltier Effects*.

Thorium. Th. El. A.W. 232.12; At. No. 90; S.G. 11.3; M. Pt. 1700° C. Grey radioactive metal. Occurs as *thorianite* (chiefly ThO_2), *thorite* (chiefly t. silicate) and *monazite sand* (containing 4–18 per cent. ThO_2). Extracted by a complex wet process, the metal being finally obtained by heating t. chloride (ThCl_4) with sodium. Used, as the metal, in X-ray tubes, glow-discharge lamps, and in measuring restricted portions of the ultra-violet spectrum.

Three-Quarter-Hard. See *Quarter-Hard*.

Tie-Line (or Tie). In an equilibrium or constitutional diagram, a line joining two compositions which can co-exist in equilibrium.

Time-Quenching. See *Interrupted Quenching*.

Time-Yield Figure. A test devised by Hatfield for assessing creep resistance value. This is represented by the stress which will produce deformation not exceeding 0.5 per cent. of the gauge length during the first 24 hrs. of the steady application of the stress, and will not cause measurable further extension of the test piece during the next 48 hrs., within the accuracy of measurement that is possible. The t.-y. test thus deduces the stress which will permit the extension of the test piece to settle down in a comparatively short time to a steady rate, a rate at which reasonable permanence of dimensions is ensured. A stress of two-thirds of the t.-y. value is regarded as the maximum safe working stress.

Tin. Sn. El. A.W. 118.70; At. No. 50; S.G. 7.29; M. Pt. 231.84° C. Bright white metal, soft, malleable and ductile, not affected by exposure to air or water at ordinary temperatures; converted at low temperatures into a powder, "grey tin", the effect being known as "tin plague". White t. occurs in two allotropic forms, tetragonal (18°–170° C.) and rhombic (above 170° C.), of s.g. 6.56. Occurs native, but chiefly as *cassiterite* or *tinestone*, SnO_2 . Extracted by reduction with anthracite, using lime or fluorspar as a flux, in a reverberatory or shaft furnace. T. is used

Tin

chiefly as a coating, applied by hot-dipping, electro-deposition or spraying, on iron and copper for protective purposes; as collapsible tubes for toilet and other preparations; foil for wrapping cheese and other food products; piping for beer, distilled water, etc. Its more important alloys are bearing alloys, solders, pewter, type metal and bronzes.

Tin-Plate Bars (or "Tin Bars"). B., approximately 15 ft. long and 10 in. by 0.5 in. in section, which are to be rolled down for the manufacture of t.-p. They are made of low-carbon steel, frequently basic Bessemer steel, which is cast into ingots of weight usually less than 30 cwt., these being rolled down and sheared in the steel works, and delivered to the t.-p. works in the form in question.

"Tin Sweat." An effect obtained during the casting of bronzes, in which beads or sometimes larger quantities of segregate are exuded from the surfaces of runners and risers, and even from those of the castings themselves. The segregate is always lighter in colour than the metal proper, and, in castings of phosphor bronze, is substantially the ternary eutectoid of copper phosphide (Cu_3P), the δ -constituent and α -solid solution. When, as frequently, lead is present, this also is largely segregated with the complex eutectoid. The appearance of t.s. is one example of inverse segregation (q.v.).

Tinning. The coating of metals and alloys with tin for protective and other purposes. Steel sheets are tinned by a hot-dip process to produce tinplate (q.v.). Electro-tinning is in increasing use for steel, any thickness desired being thus obtainable. Coatings considerably thinner than that produced in the hot-dip process, but sufficient for the purpose, can be obtained, with considerable economy in tin. The electrolyte is usually an alkaline sodium stannate solution, and the matte surface of the deposited metal can readily be polished by light rubbing. Hot-dip t. is used to facilitate adhesion of white metal bearing alloys to the backing shells of gunmetal, steel or cast iron.

Tinplate. Steel sheets coated with a protective layer of tin. The white-pickled sheets are passed, by means of rollers and guides, into a bath of molten tin, contained in a "tin pot", the surface of the metal in this being divided by a bridge into two parts. One, the feed or entry end, is covered with a flux of zinc chloride, to ensure adhesion of the tin. The other, or exit end, is covered with molten palm oil, the rollers working in this portion being provided with brushes, to ensure even distribution of the tin coating; while, at the same time, the temperature of the plate is so reduced as to prevent undue oxidation of the coating when exposed to air. The coating is

usually less than 0.001 in. thick; but any desired thickness can be obtained by the process of electro-tinning.

Tipping. The brazing or welding of hard alloy inserts (high-speed steel or sintered carbide tips) on to carbon steel shanks, an economy measure to conserve the scarcer and more expensive materials. *See also* **Hard-Surfacing.**

Titanium. Ti. El. A.W. 47.90; At. No. 22; S.G. 4.8; M. Pt. 1800° C. Hard dark-grey metal closely related to silicon; brittle in cold, but can readily be worked at a red heat if free from carbon. Occurs as *ilmenite* or *titaniferous iron ore*, FeTiO_3 ; *rutile*, *brookite* and *anatase*, TiO_2 ; *sphene* or *titanite*, $\text{CaO} \cdot \text{TiO}_2 \cdot \text{SiO}_2$, etc. Extraction complex and difficult, the metal being finally obtained by reducing the dioxide with carbon in the electric furnace; by the thermit process, or, in a pure state, by reduction of the dioxide with calcium. Used, as the metal, for electric lamp filaments; as the carbide and nitride, in sintered cutting tools; as ferro-titanium, as a deoxidizer and denitrogenizer in the manufacture of steel, in arc-welding electrodes, and, alloyed with nickel and cobalt, in the alloy konel (a heat-resisting alloy used for filaments for radio valves); as an alloy, in chrome-nickel stainless steels (where it forms a stable carbide of low solubility), aluminium alloys, aluminium bronze, copper alloys, etc.

Tocco Process. *See* **Induction Hardening.**

Tool Steel. (1) Carbon t.s. is crucible cast s., the carbon content or "temper" (q.v.) varying from about 0.75 per cent. ("Die Temper"), for dies for drop forging, up to about 1.3-1.5 per cent. ("Razor Temper"), for razors, special lathe tools for turning chilled rolls, etc. (2) Alloy t.s. is almost exclusively high-speed s. (q.v.). Other special alloys, as sintered carbides, cobalt-chromium-tungsten alloys, etc., are also used for cutting purposes, but these are not s.

Toolweld Process. A p. in which electric fusion welding is used to build up the cutting edges on lathe tools, milling cutters, etc., which have become worn or damaged in use. The electrode is of high-speed steel, the air-hardening capacity of which provides a cutting edge of great hardness (not less than 55 Rockwell C, 545 Brinell or 70 Shore Scleroscope hardness). This not only retains its hardness to temperatures up to about 1000° F. (or 540° C.), but is also satisfactorily shock-resistant. The high-speed electrode may be used for depositing on a tool either of carbon steel or high-speed steel. Similarly, a plain carbon tool can be furnished with a cutting

Top

edge of high-speed steel at a cost much below that of a high-speed tool.

“Topping.” See Ending.

Torsion. The shear produced by the rotation of each layer of a body in relation to adjacent layers. Pure shearing stress is obtained in the cross-section of a cylindrical rod or shaft by applying equal and opposite couples at its ends, if the axis of the rod is also the axis of the couples. Within the elastic limit, the torsional shear stress varies from zero at the centre to a maximum in the outer layer, torsional strain being similarly proportional to the distance from the axis.

Torsion Test. A test, which can conveniently be carried out in the usual lever machine, consisting in twisting a suitable test piece to destruction, and plotting the torque or twisting moment against the amount of deformation, measured in degrees of twist. The values of torque for elastic limit and ultimate stress are converted into terms of shear stress by the application of the usual formula for shear stress in twisted shafts, viz.:

$$\text{Shear Stress} = \frac{16T}{\pi D^3}$$

where T = Torque and D = Diameter. This formula applies strictly only to conditions within the elastic range. The stress value obtained from this formula by substituting the maximum torque value is known as the “apparent maximum shear stress” for the material. It is recognized that the formula does not give the real maximum shear stress which the material can endure, and that a more likely value for this quantity is obtained by using the formula:

$$\text{Shear Stress} = \frac{12T}{\pi D^3}$$

the value thus obtained being known as the “probable actual maximum shear stress”.

Toughness. A term used very loosely, sometimes to express ductility (q.v.), or even a combination of strength and ductility; but preferably restricted to denote that quality of a material, usually steel, characterized by a high notched-bar value. Steels showing a high notch-value are tough; those showing a low notch-value are brittle; while either class may be ductile. Cf. Notch Brittleness, Notch Sensitivity, etc.

Transformation (or Transition). A change of constitution at a particular temperature, usually attended by a change of structure,

which, however, may not always be microscopically visible. The temperature at which a t. occurs is known as a t. point or change point. The position of this point on heating may be considerably higher than that of the corresponding point on cooling. *See also Metastable Equilibrium*, etc.

Transformation Range. The transformation range on heating is the temperature interval in which austenite forms in an iron-carbon alloy. The t.r. on cooling is the temperature interval in which austenite disappears. Distinction must be made between the two ranges. They may overlap, but never coincide. The limiting temperatures of the r. depend on the composition of the alloy and, particularly for the cooling, on the rate of change of temperature. (Prop. Std. Defn., A.S.T.M., 1942.)

Transition, Curve of Complete. In a constitutional diagram, the curve delimiting one side of a two-phase field, the side on which the particular change has just been completed. It will be clear that the curve of complete t. on cooling will be the curve of incipient t. on heating; and *vice versa*.

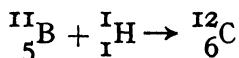
Transition, Curve of Incipient. In a constitutional diagram, the curve delimiting one side of a two-phase field, the side on which the particular change is just beginning to occur. *See also Transition, Curve of Complete*.

Transition Products. Products resulting from the transformation of an original constituent, the rate of cooling deciding which one or more of a series of various decomposition products shall result. Thus, austenite is transformed, in cooling through the critical range, into one or more of various t.p., martensite, troostite, sorbitic pearlite, etc., the rate of cooling deciding which of these will be formed. *See also Critical Cooling Rate*, etc.

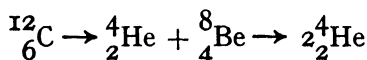
Transmutation of Elements. The changing of one chemical element into another, involving an alteration in nuclear mass. In radioactive nuclei, such changes are spontaneous, and the rate of disintegration cannot be controlled by artificial means. When disintegration of the atom involves the emission either of an α -particle or β -particle, a new chemical element results. Thus, uranium, radium and thorium are spontaneously and continuously disintegrating, the final product being in all cases lead. Similar changes can also be brought about by bombarding nuclei with various "atomic projectiles" (q.v.), when the energy so liberated may be 500 times as great as that of the bombarding particle, but some 100,000 particles may have to be "fired" before a hit is obtained;

Tra

and atomic bombardment is so far quite unprofitable as a source of energy. For example, if a proton is "captured" by a nucleus of boron of mass 11, a nucleus of carbon of mass 12 is obtained, thus :



the masses and charges of the compound nucleus being the sum of the individual masses and charges. The carbon nuclei so formed are in a violently excited state, and some may revert to stable carbon nuclei, by the emission of γ -radiation with an energy of 15,000,000 volts. Others within 10^{-21} of a second emit an α -particle, to produce a nucleus of beryllium, which, being also excited, may break up into two α -particles. The carbon nucleus has thus broken up into three equal fragments :



By suitable means, magnesium has been converted into aluminium, and this in turn into silicon. It may be noted that gold should result from the emission of an α -particle from the mercury atom by electrical bombardment, thus fulfilling—at some expense—the dream of the mediæval alchemist. So far, however, this result has not yet been achieved with certainty. *See also Radioactivity, Atomic Energy, Periodic Table, etc.*

Transverse Test. A test, used for cast iron, in which a bar, supported as a beam, is loaded in the mid-position until it fractures, the breaking load, and frequently the deflection before fracture, being determined. British standard test bars are round, and vary in diameter with the thickness of the casting represented. If the span is L inches, the breaking load W tons, and the modulus of section Z , the modulus of transverse rupture is $WL/4Z$ tons per sq. in. For a round bar, Z is $0.0982d^3$, where d is the diameter of the bar.

Triplexing. Steel manufacture by the progressive treatment of metal in a cupola, a converter and an electric furnace (or sometimes an open hearth), in the order stated. Thus, cast iron from the cupola may be run into ladles, desulphurized and then carried to the converter in transfer ladles. On conversion into steel, no additions are made in the converter, additions of manganese, silicon and alloys, as required, being made in the electric furnace, which is, primarily, a holding and mixing unit. *Cf. Duplexing.*

Troostite. A characteristic dark-etching and apparently structureless decomposition-product of martensite, appearing as nodules, which often indicate the original austenite grain boundaries. T. is

produced while cooling through A_{r3} , when quenching at a rate not sufficiently rapid to maintain the steel in the martensitic state, but rapid enough to prevent the production of sorbite. It can be obtained by quenching while cooling through the A_{r3} point; or, alternatively, by tempering martensite at a low temperature, considerably below A_{r1} , and in the 200° – 400° C. range. T. consists of a very finely dispersed aggregate of almost ultra-microscopic particles of ferrite and cementite. With a Brinell hardness of about 450, it is considerably softer than martensite, and is also tougher. On tempering t. at higher temperatures, it changes by indistinguishable degrees into sorbite (q.v.).

Troosto-Martensite. A constituent obtained in the tempering of austenite, with a structure and properties intermediate between those of martensite and troostite (q.v.).

Troosto-Sorbite. A constituent obtained in the tempering of austenite, with structure and properties intermediate between those of troostite and sorbite (q.v.).

True Tensile Stress (or Real Fracture S.). This value, represented by P/A , is a measure of the actual (minimum) load, P , required to cause fracture of a tensile test-piece, in relation to A , the cross-sectional area at fracture. It differs from the ultimate stress (q.v.), which relates the *maximum* load before fracture to the original cross-sectional area of the test-piece before loading. See **Load-Extension Diagram and Stress-Strain Diagram**.

Tungsten. W. El. A.W. 184.0; At. No. 74; S.G. 19.2; M. Pt. 3399° C. Hard steel-grey metal, a good conductor of electricity and highly resistant to corrosion. Occurs chiefly as *scheelite*, CaWO_4 , and *wolfram* or *wolframite*, FeWO_4 . Extracted, usually from wolframite, by a complex process, the metal being obtained, as a grey powder, by the reduction of the pure oxide (WO_3) in silica tubes by hydrogen at 850° C. The powder is compressed and sintered in hydrogen at 1300° C. to produce a bar, through which a heavy current is passed, to raise its density from about 12 to 19. The bar is swaged at 1500° C. and finally drawn through dies of tungsten carbide, and then of diamond, into wire, of purity 99.75 per cent., or over. Used as the anti-cathode in X-ray tubes; filaments in electric-lamps; for magneto and other contacts; and as an electro-deposited coating of high corrosion-resistance on brass and other base metals, for laboratory ware and other purposes. In steel, t. confers great hardness after heat treatment, this being maintained at high temperatures, t. being thus an essential constituent in high-speed tool steels. It is also a constituent of magnet

Two

steels and the hard-facing alloy, Stellite. Tungsten carbide is the major constituent of sintered carbide cutting tools. A t. alloy containing 4 per cent. nickel and 6 per cent. copper has a s.g. of 16.5 and a higher absorption coefficient for X-rays than lead, being thus more effective than lead for protection purposes in radio-therapy ; while its high density makes it very suitable for balancing internal combustion engine crankshafts.

Twinned Crystals or Twins. Neighbouring crystals in which one or two sets of the crystalline axes are parallel, but the other or others are not. T.c. have always one face in common, being symmetrical with respect to a plane, termed the *twinning plane*, which is not a plane of symmetry for the separate crystals. In their internal arrangement and symmetry, they are thus mirror-images of each other. On microscopic examination, the boundaries between adjacent crystals are seen as parallel straight lines across the crystal grain. Two parallel crystals can be made to assume a twinning position by the rotation of one of them through 180° about an axis, normal to the twinning plane, known as the *twinning axis*. Strain- or mechanical twins are those produced by deformation only (as with tin or zinc), when slip also occurs. Annealing twins are those produced by the annealing of cold-worked metal, as brass and austenitic steels. The annealing of cast metal which has not been cold-worked does not give rise to twinning. Cf. **Neumann Bands**.

Twisting Test. A test for wire, which is gripped by two vices, and twisted by one of these at a rate not exceeding one revolution per second. The number of twists, or complete turns, before fracture, is a measure of the quality of the material. The number of twists is determined by means of an ink mark which produces a spiral on the wire during torsion. The complete number of twists must of course be visible between the vices. The torsion test (q.v.) is also a twisting test.

U

Ultimate Stress (**Ultimate Tensile Stress (U.T.S.)**, **Maximum Stress** or **Tensile Strength**). The maximum tensile stress which a material is capable of developing, determined by relating the maximum load shown before fracture to the original cross-sectional area of the test piece. The u.s. is thus a purely arbitrary value, for fracture can be produced at a load lower than the maximum load, while the area on which it is determined is the initial cross-sectional area, and not that at the fracture. *See True Tensile Stress.*

Ultrasonics (or **Supersonics**). That branch of science concerned with wave frequencies inaudible to the human ear. Vibrations above 17,000 cycles per second, or 17 kc., represent the upper limit of human hearing. In their shorter reaches, ultrasonic waves merge with radio and finally with light waves. Among applications of u. are the so-called "inaudible dog whistle" and the submarine detector. While metals have a high permeability both for sound and ultrasound, cracks and other defects hinder the passage of these waves, causing sound absorption and reflection. The shorter ultrasonic waves can thus be employed to locate the position of defects in metals and alloys, and have already been applied on a production scale for detecting unsoundness in forged duralumin propeller blades. The method is superior to radiography, being capable of detecting laminations which do not represent a sufficient difference in density to be detectable by X-rays.

Undercooling. *See Superfusion.*

Underpoled. *See Poling.*

Up-ending. A forgeability test for brass bars and sections, in which a longitudinal test piece having a length equal to the diameter or width across the flats of the bar or section shall, without cracking, withstand being placed on end and compressed while hot until reduced to 20 per cent. of its original length. (B.S.S. Nos. 1001-2-1941.)

Upsetting (or **Jumping-Up**). A process of forging, in which the cross-sectional area of a billet, or other part, is increased (either generally or locally), and the length correspondingly reduced, by blows or pressure applied at the end. The part may either be free to expand laterally, or may be enclosed in a former, so that the desired

Ura

shape is produced. U. is used in the manufacture of rivets, valve heads, etc.

Uranium. U. El. A.W. 238.07; At. No. 92; S.G. 18.685; M. Pt. 1689° C. Hard, lustrous silvery-white radioactive metal, unaffected by air at ordinary temperatures, but burning brilliantly at 170° C. Reacts with boiling water. Occurs as *pitchblende* (U_3O_8) and *carnotite*, u.-potassium vanadate. Extraction very complex and costly, but u. is a by-product of the recovery of radium and vanadium, the cost being thus reduced. U. is finally obtained by reduction of the chloride (UCl_4) with sodium in a steel bomb screwed down tightly. U. is used in X-ray tubes, glow-discharge lamps, and in measuring restricted portions of the ultra-violet spectrum. Ferro-u., made in the electric furnace, is used as an alloy in steel, to increase strength and hardness, with little prejudice to ductility. The 67 u. : 33 per cent. nickel alloy has a remarkable resistance to attack by acids, including aqua regia.

V

Vacuum Casting. The creation of a partial vacuum in a mould, after the metal has been poured into it, in order to facilitate the removal of gases and hinder the production of blowholes or other cavities in the solid metal.

Vacuum Fusion. Melting in an evacuated container.

Valency (or Valence). The combining power of an atom, measured by the number of hydrogen atoms with which it will unite; or which it will replace. Thus, in water, H_2O , oxygen is bivalent. Since the equivalent of an element is the weight which combines with, or replaces, unit weight of hydrogen, $v. = \text{atomic weight} / \text{equivalent}$. The elements are classified into eight groups, according to their $v.$; or into nine groups, if the inert gases and radioactive emanations, of zero $v.$, are included. The $v.$ of an element may vary either in its compounds with the same or with different elements. The *maximum* $v.$ of an element is the greatest $v.$ it is known to exhibit; the *active* $v.$ is that actually occurring in a particular compound. When two atoms of the same element are united by multiple bonds ($q.v.$), the element appears to show a $v.$ lower than its maximum $v.$ Multiple bonds thus contain latent bonds. When broken, each of these gives rise to *two* available bonds. Compounds showing multiple bonds are *unsaturated*; and atoms can be added, to form a *saturated* compound. $V.$ may also be classified as positive or negative, the positive $v.$ being attracted to the cathode and the negative to the anode of an electrolytic cell. A univalent atom becomes stable by losing or gaining one electron. *See also* **Electronic Theory of V.**

Valency, Electronic Theory of. *See* **Electronic Theory of V.**

Valency Electrons. The outermost shell of $e.$ in an atom, the $v.$ group, on which the chemical and physical properties of the material entirely depend. *See* **Electronic Structure, Electronic Theory of Valency, etc.**

Vanadium. $V.$ El. A.W. 50.95; At. No. 23; S.G. 5.5; M. Pt. $1720^\circ C.$ Hard brilliant-white metal, resembling antimony; very brittle; unaffected by air or water at ordinary temperatures, but combines vigorously with both oxygen and nitrogen when heated. Occurs as *vanadinite*, $3Pb_3(VO_4)_2 \cdot PbCl_2$; *patronite*, V_5S_8 , with hydrocarbons and free sulphur; *mottramite*, $(PbCu)_3(VO_4)_2 \cdot 2PbCu(OH)_2$;

Vap

carnotite, a hydrated vanadate of uranium and potassium; and other minerals, iron ores, etc. Extracted from patronite by roasting, when a clinker is obtained containing about 40 per cent. of the oxide, V_2O_5 , practically free from sulphur, this being reduced to metal, either by carbon in the electric furnace; or by the thermit process. In steels, added as ferro-v., v. is a powerful deoxidizer; also increasing the strength, hardness and fatigue resistance of quenched carbon and low-alloy steels, being often used, to the extent of 0.15 per cent. or so, in chromium steels for automobile axles, coil springs and other purposes. The effect of tempering in the range 500°–600° C. is reduced by the presence of v. in proportion not above 0.35 per cent. The use of 1–1.5 per cent. of v. in high-speed steel increases air-hardening propensity and cutting quality. In cast iron, v. is a hardener, increasing the tensile, transverse and compression test values. V. is also used in some non-ferrous alloys; as in Y-alloy, to refine the grain, improve casting quality and increase the response to heat treatment.

Vaporization, Latent Heat of. See Latent Heat of Vaporization.

Veining (or Sub-Boundary Structure). A network of boundaries, known as v., found within the crystals of various pure metals and many copper alloys, and due to the precipitation from solid solution, in a network form, of the oxide of the metal during cooling. At low magnifications, the lines are continuous, and may sometimes appear as sharp as the real boundaries. On higher magnification, the veins are seen to be discontinuous. The orientation of the sub-grains is nearly but not quite uniform in each crystal. Where mechanical twins are present, the v. passes through these unchanged. Annealing twins have usually, but not always, their own system of v. When the oxide responsible for v. can be reduced by hydrogen, v. can be removed by a high-temperature treatment with hydrogen, either in the solid or liquid state. Similarly, quenching, which maintains the oxide in solution, suppresses v., which can, however, be released once more by annealing. S.-b. structures are similar in appearance to v., but are due to the precipitation, during cooling, of an intentional constituent of the alloy, less soluble at lower temperatures. For a s.-b. structure to be found, only a small critical quantity of the s.-b. constituent must be present, combined with a critical rate of cooling, the phase being otherwise deposited in more massive form. S.-b. structures are unaffected by hydrogen treatment.

Velocity-Sensitivity. See Notch S.

Vickers Hardness Test. See Diamond Pyramid H.T.

Vitreous. *See* Amorphous.

Void. (1) A cavity, *e.g.*, the shrinkage cavities (q.v.) produced in cast metals during freezing, if the volume lost in solidification is not filled by further liquid metal supplied from above. (2) In Powder Metallurgy, an unintentional empty space in a sintered compact (A.S.M. Defn.).

von Mises-Hencky Hypothesis. A theory, advanced as a criterion of failure, assuming that failure occurs at a constant value of the energy of shear strain, *i.e.*, potential energy stored in the material due to purely elastic strains excluding tension or compression.

W

Weathering. *See* Seasoning.

Weld. A junction between two pieces of metal in which both surfaces to be joined have been raised to a plastic or liquid condition by the application of heat with or without added metal and with or without application of pressure. (B.S.S. No. 499—1939.)

Weld Decay. A type of intercrystalline corrosion shown by austenitic 18 : 8 chromium nickel steels, and due to the precipitation of carbides, chiefly chromium carbide, Cr_4C , at the austenite grain boundaries. This may result from heating the steel in the temperature range, $900^\circ\text{--}500^\circ\text{C}$., as in welding (hence the term); by slow cooling through this range; or under service conditions where such temperatures may occur. Round each carbide particle is a region depleted of chromium and of much lower corrosion resistance; so that intercrystalline attack may readily occur. The presence of free carbide can be detected by skilled metallographic polishing and etching. Susceptibility to w.d. can be determined by subjecting to an acid corrosion process, usually the Strauss test, the alloy being first heated in the sensitizing zone, and then exposed to the attack of a 10 per cent. sulphuric acid–10 per cent. copper sulphate solution for a sufficient period; when, if there is intercrystalline attack, slight bending will lead to a roughening of the surface; while, in extreme cases, the metal will disintegrate completely. Metal thus corroded will also sound “dead”, instead of giving the usual ring when struck. Liability to w.d. is reduced by lowering the carbon content, to retard carbide precipitation; while it can be prevented by the addition of a stabilizing element, such as columbium (in proportion at least ten times the content of carbon), when stable columbium carbide is produced, instead of chromium carbide, and the alloy is no longer liable to w.d. Effective combination of the columbium with carbon can be obtained, after the usual heat treatment—involving rapidly cooling from about 1100°C .—by further annealing at 900°C . *See also Austenitic Steels, Stabilizers, etc.*

Welding, Atomic Hydrogen. A process in which hydrogen, dissociated by the heat of an electric arc, supplies the welding heat and shields the molten filler metal. An alternating current arc is maintained between two tungsten electrodes, and a stream of ordinary (molecular) hydrogen is passed through the arc, so as to envelop the electrodes. The intense heat of the arc decomposes the molecular hydrogen into atomic hydrogen, which has absorbed a

great quantity of heat. This atomic hydrogen is continuously displaced from the arc by the molecular hydrogen being supplied. Being removed from the intense heat of the arc and becoming cooler, it recombines to form molecular hydrogen, giving up at the same time the heat absorbed in its dissociation. This heat transfer affords a rapid localized heating available for welding. The hydrogen provides a reducing atmosphere, ensuring a thoroughly deoxidized weld and reducing electrode consumption. The process is used for welding alloy steels, brasses and bronzes, aluminium and nickel alloys, etc.

Welding, Autogenous ("Self-Generating"). A term, now obsolescent, covering w. processes in which the joint is effected by heating the parts to such a temperature that they liquefy and fuse together, no mechanical means being used to unite them. The term also includes processes in which a filler rod of similar composition is employed to supply beads of molten metal which are gradually built up into a run. It will be seen that a.w. covers several quite distinct fusion w. processes; but oxy-acetylene w. was the process commonly understood by the term. With the great increase in the variety of w. processes, and the need for a precise description of each of these, the term has nowadays very little significance or usage. *See Fusion W. and Gas-Blowpipe W.*

Welding, Bronze. A process of welding where metals are united by melting bronze or brass filler rods into the joint. (B.S.S. No. 499—1939.)

Welding, Carbon-Arc. An electric-arc welding process where a carbon electrode is used, and filler metal added if required. (B.S.S. No. 499—1939.)

Welding, Electric Arc. A fusion-welding process where the welding heat is obtained from an electric arc formed either between the parent metal and an electrode, or between two electrodes with or without the use of shielding gases. (B.S.S. No. 499—1939.)

Welding, Forge. A process of welding metals by means of manual or mechanical work where the surfaces to be joined are heated to a plastic state. It includes *blacksmith welding* (manual hammering), *hammer welding* (mechanical hammering) and *roll welding* (employing mechanically operated pressure rolls). (B.S.S. No. 499—1939.)

Welding, Fusion. A process of welding independent of mechanical pressure or hammer blows where the surfaces to be

Wel

joined are melted with or without the addition of filler metal. It includes *gas-blowpipe welding* (q.v.), *electric-arc welding* (q.v.), *atomic-hydrogen welding* (q.v.) and *fusion thermit welding* (where the heat for fusion is obtained from liquid steel resulting from a thermit reaction, the steel so produced being used as the filler metal). (B.S.S. No. 499—1939.)

Welding, Gas-Blowpipe. A fusion-welding process where the welding heat is produced by a gas flame. Oxygen and acetylene are understood to be the gases employed unless otherwise stated. A neutral flame is one where the gases are supplied in proportion producing perfect combustion. A carbonizing or reducing flame is one having a carbonaceous gas in excess of that required to produce a neutral flame. An oxidizing flame is one having oxygen in excess of that required to produce a neutral flame. (B.S.S. No. 499—1939.)

Welding, Metal-Arc. An electric-arc welding process where the electrode used is a metal rod or wire, which when melted becomes the deposited metal in the weld. (B.S.S. No. 499—1939.)

Welding, Pressure. A process of welding metals by means of mechanical pressure whilst the surfaces to be joined are maintained in a semi-molten state. It includes *resistance welding* (q.v.) and *pressure-thermit welding* (where the welding heat is produced by the reaction of thermit). (B.S.S. No. 499—1939.)

Welding, Projection. A modified form of spot w. (q.v.), differing only in the method by which the w. current is concentrated at a spot or spots. Thus, with sheet, projections or pimples are made on one of the sheets. On the application of the current, the heat is localized at the projection, which, when raised to welding temperature, collapses under the applied pressure, and a local weld is made.

Welding, Resistance. A pressure welding process where the welding heat is produced by the passage of an electric current across the contact areas to be welded. It includes: (a) *Resistance Butt Welding*, where the parts are butted together and contact is maintained under pressure until the weld is completed; (b) *Resistance Flash Welding*, where an arc is struck and maintained between the parts until the welding heat is attained, after which the current is cut off and the weld made by forcing the parts together; (c) *Resistance Seam Welding*, where the weld is made by the aid of two contact rollers, or a contact roller and a contact bar; (d) *Resistance Spot Welding*, where overlapping parts are welded at one or more spots by the aid of contact points; (e) *Resistance Percussive Welding*,

where a heavy electric current is discharged momentarily across the contact areas, and a hammer blow to force the work together is applied simultaneously with or immediately after the electrical discharge. (B.S.S. No. 499—1939.)

Welding, Seam. A type of resistance w., in principle similar to spot w. (q.v.), where, however, the electrodes are replaced by contact wheels, continuously revolving and carrying intermittent current impulses, so as to produce a series of spot welds. The spacing of these welds is determined by the machine and the form of control equipment employed, and the spots can be arranged to overlap (in which case a pressure-tight seam is produced) or spaced apart. (Defn. of the Advisory Service on W.—W. Mem. No. 4A.)

Welding, Shielded Arc. A metal-arc or carbon-arc welding process where the arc is surrounded by, and the molten weld metal is enveloped in, a protective gas discharged under pressure. (B.S.S. No. 499—1939.)

Welding, Spot. A type of resistance w. (q.v.), in which two sheets or plates are joined by welds formed at the interface between them at a suitable number of spots. At these, suitable pressure is applied by the electrodes, the heat required to raise the metal to w. temperature being obtained by the passage of the w. current through the resistance provided by the components.

White Annealing. A process, applied to tinplate, precisely as black a. (q.v.), but carried out at a much lower temperature; after which the slight oxidation caused by a. is removed by pickling in dilute acid.

White Iron. See Cast Iron.

Widmanstätten Structure. A type of s. first observed in meteorites, and shown by overheated and therefore coarse-grained alloys which have been cooled slowly without being worked. A W.s. is that in which a new phase separates, not only at the crystal boundaries of the original phase, but also along definite crystallographic planes, giving rise to a characteristic angular s., of poor mechanical quality. With slowly-cooled hypo-eutectoid steels in which the austenite grain size is not too large, ferrite is rejected only to the grain boundaries, the s. finally exhibiting a ferrite network round grains of pearlite. With less slow cooling and a large austenite grain size, the rejected ferrite cannot diffuse entirely to the boundaries, but separates also in long continuous plates between the cleavage planes. In steel, a W.s. constitutes evidence of low

Wip

fatigue—and shock—resistance, and should be corrected by heat treatment. Similar structures are shown by other alloys.

“Wiped Joint.” The process of jointing lead pipes by means of Plumber’s Solder (Lead, 66.66 per cent.; tin, 33.33 per cent.), an alloy having a long plastic or pasty range, of nearly 70° C., during which the alloy is partly solid and partly liquid, a condition readily permitting the application and smoothing of the alloy which constitutes the process in question.

Wire. A very thin metallic thread, generally round in section, obtained in pieces of considerable length by drawing in the cold through tapered holes in a draw plate or die. So small a section cannot be produced by rolling (q.v.).

Wöhler Fatigue Test. A t. for determining the endurance or fatigue limit (q.v.). The t. piece is a horizontal rotating cantilever, with the free end loaded, when the upper side is in tension and the lower in compression, any portion of the bar, apart from the neutral axis, being thus subjected to alternating tension and compression once in each revolution. The extreme outer portion of the bar is subjected to maximum stress, the stress at any other point in the section being—for elastic loading—proportional to its distance from the neutral axis. The t. bar, and the weight, spring or other means of loading being free from vibration, the stresses can be calculated from the bending moment of the applied load. If one plots, either the maximum applied stress, or the range of stress, as the ordinate, and the corresponding number of repetitions of the cycle as the abscissa, one obtains a regular curve which tends to become parallel with the abscissa as the intensity of stress diminishes. If it actually does become parallel, it must indicate a limiting stress value; which, if not exceeded, cannot cause failure even after the application of an infinite number of the stress cycles.

Work-Hardening (or Strain-Hardening). The increase in hardness obtained on straining a ductile metal plastically. A further increase in hardness can be obtained on ageing (q.v.) at ordinary or slightly elevated temperatures. The effects of w.-h. can be removed by annealing at a temperature and for a time appropriate to the metal (or alloy) being treated. *See also Cold Working, etc.*

Worms. *See Stretcher Strains.*

Wrought Iron (Malleable Iron). I. obtained by the refining of pig i. (q.v.) in a puddling or reverberatory furnace. The impurities carbon and silicon are gradually oxidized and removed from the

molten pig i. by the action of hematite iron ore or mill scale (i. oxide) added to the melt, the furnace lining being generally composed of similar material, while air is also admitted to promote the reaction. The reduced i., which now has a much higher melting point, forms in pasty or semi-solid globules which are collected together into balls by means of i. rods manipulated by the puddler. These balls contain mechanically-included semi-liquid slag (silicate of i.). On removal from the furnace, the ball is put through a squeezer, or worked by means of a steam hammer, to remove much of the slag, the product being then known as puddled bar in this country and muckbar in the U.S.A. By cutting up, piling, heating and re-rolling, merchant bar, of superior quality, is obtained; while, by further similar processes, best, best-best or treble-best i. can be produced. Apart from its slag content, w.i. has a composition like that of low-carbon steel, into which it is converted on fusion. The presence of the slag, which is elongated into "threads" on forging or rolling, promotes hot-working and forge-welding; also restraining grain-growth. In cold-working, particularly in bending, the fracture of the brittle slag may initiate a crack. It increases machinability by preventing the production of long turnings; too much leading, however, to excessive tool wear. W.i. has a comparatively good corrosion-resistance, due, not to the slag, but to its content of dissolved oxygen, which considerably increases electrode potential (q.v.). W.i. has a strength of some 22-24 tons per sq. in., with high ductility. It shows a great capacity for quickly recovering from overstrain and is thus not permanently damaged by sudden shock, being therefore used for anchors, chains, crane hooks, etc. For chains, hooks, etc., the effects of work-hardening are corrected by periodical annealing.

X

X-ray Crystal Analysis. The determination of c. structure by means of X-rays. Considering a c. as being built up from one of its faces, the atoms of which are situated at the points of a geometric framework known as a lattice (q.v.), the c. as a whole is made up of a succession of such arrangements. The arrangement is substantially constant for any one material, but differs for every other material. The atoms situated at the lattice points are disposed at distances from each other of the same order as, but a little greater than, the w.-l. of X-rays. When a fine pencil of X-rays of single w.-l. traverses a c. in which there is this regularity of arrangement, the atoms deflect the rays just as visible light is diffracted by a ruled grating; and, just as in the second case, the number of lines per inch can be optically determined; so, by X-ray c.a., can one determine the distances apart of the planes which constitute the lattice, and of the different atoms situated in these planes.

X-ray diffraction in a crystal is frequently termed "reflection"; but, for a given crystal plane, there is only one angle of incidence of a monochromatic X-ray pencil, of w.-l. λ , at which there is maximum reinforcement of the scattered wavelets from three (not co-planar) rows of atoms, the angle given by the Bragg equation:

$$n\lambda = 2d \sin \theta$$

where n is a whole number and d the distance between successive rows.

The effect of X-ray diffraction is to give rise to an interference pattern, which can be obtained: (1) By keeping the c. fixed and altering the w.-l. continuously, when the sphere of reflection sweeps out a volume of the reciprocal lattice containing some points. In the Laue method, the c. is illuminated by means of a narrow pencil of white X-rays (*i.e.*, one containing a wide continuous range of w.-l.), the diffraction pattern—appearing as a series of spots—being generally recorded photographically. (2) By using a fixed w.-l. and varying the orientation of the c., either (a) by oscillation or rotation about one axis, when points of the reciprocal lattice sweep through the sphere of reflection; or (b) by using the crystalline substance under examination in the form of a very fine powder, with random orientation, adherent to a glass fibre or a hair, situated on, and usually rotating continuously about the axis of the cylindrical camera during exposure. This is the commonly used *Powder Method*, developed independently by Hull and by Debye and Scherrer. Of the many small c. in the path of the incident pencil, there are always a sufficient number of such orientation as to reflect the X-ray pencil, of single w.-l., so as to give rise to a number of

diffraction cones, which relate to the atomic planar distances found in the characteristic c. structure. These cones of diffraction can be recorded on a photographic film by various means. Thus, a flat film behind the specimen set perpendicular to the direction of the X-ray pencil shows a series of concentric rings. Or the *Back Reflection Method* may be used, the film being placed so that the primary X-ray pencil must pass through the film before impinging on the specimen. The usual method employs a cylindrical powder camera, in which narrow strips of film on its periphery nearly surround the specimen, mounted on its axis. The X-ray pattern then consists of slightly curved lines, is distinctive for each crystalline element or compound, and can thus be used for identification purposes. Changes in the appearance of these interference lines also afford considerable information as to the structure and quality of the material being examined. The existence of a preferred orientation in various alloys (but not in steels) is indicated by periodical variations of thickness of the lines, which now show a number of diffraction arcs symmetrically distributed around them. With increase in grain size, the lines break up into a widely scattered arrangement of individual spots, when the size of larger grains is approximately proportional to the dimensions of the spots, the geometry of the projection being suitably taken into account. The existence of residual stresses causes lattice strain, when the individual stress components can be evaluated by the measurement of lattice strain in two different directions, both lying in the vertical plane containing the required stress component. By such methods the effectiveness of an annealing operation can be determined.

X-ray Tube (Hot Cathode Type). A glass envelope, continuously evacuated, containing two electrodes, between which a high potential, 30,000 volts or more, is maintained by means of a high-tension transformer; with sometimes a valve rectifier. The cathode is a tungsten filament, surrounded by a metal cap or hood, and heated to such a temperature that a stream of electrons is evolved, these being focused, by means of the molybdenum focusing cap, on a small rectangular area on the face of the positive electrode, the anti-cathode or target. For radiographic work, the target is generally a hollow water-cooled block of copper, with a small tungsten disc set into its face. The water-cooling is required to remove the heat into which a good deal of the energy of the incident electron beam is converted. When viewed at an incident angle of about 20° , the rectangular source of the primary X-ray beam is foreshortened to a square; while, by viewing at almost glancing angle, a source of X-rays effectively approaching a single line is obtained. Penetration into the metal being examined radiographically is controlled by the X-ray tube voltage, increase in which increases the proportion of the

X-r

shorter more penetrating waves. In general, the voltage should be adjusted to the lowest value at which penetration is adequate. Further, the distribution of the w.-l. or "colour" can be varied by the interposition of suitable metal filters, when the components of longer w.-l. can be eliminated. This greatly reduces the amount of scattering and secondary radiation from the specimen, a further reduction being obtained by the use of thin sheet lead intensifying screens on both sides of the X-ray film. There is thus a considerable gain in definition of the image at the higher voltages. For X-ray crystal analysis (q.v.), a variety of interchangeable targets, each faced with a different metal, are employed, so that different w.-l. can be made available. A demountable tube, in which the electrodes can readily be detached from the main body of the tube, and replaced by new ones, is most suitable for this type of work, for which the tube need not be operated at voltages above 60-70 kilovolts. *See also Cathode Ray.*

X-rays. Electromagnetic waves, produced in an X-ray tube (q.v.), and similar to those of light, from which they differ only in their much shorter w.-l., of the approximate order of 10^{-8} cm., and varying between limits of about 10^{-8} , for "soft", and 10^{-10} cm., for "hard" X-rays. They are capable of penetrating freely into many metals, as aluminium and magnesium; and to some extent into steel, but they are absorbed to a considerable extent by lead or platinum. They are thus used in radiography (q.v.); also in determining the structure and properties of crystals. X-radiation is substantially of two kinds, "white" or continuous spectrum radiation, and a line radiation, the w.-l. of which is characteristic of the radiating element. It is the first which has radiographic application, in that the penetration of a heterogeneous X-ray beam becomes greater as the lower limit of w.-l. decreases; while, in the continuous spectrum, there is a sharp lower limit of w.-l., depending only upon the applied voltage and decreasing as this increases. *See also X-ray Crystal Analysis.*

Y

Yield Point. In a tensile test, the load, per unit of original cross-sectional area, at which there is a definite and well-marked visible extension in gauge length without any increase in load. Discrimination is now often made between the upper and lower y.p. The upper y.p. is the maximum stress reached before a marked elongation occurs, its value varying with the degree of surface finish, the shape of the test piece (particularly the degree of change of section) and the rate of loading. The lower y.p. is the stress giving rise to the great extension shown characteristically by mild steel and wrought iron. This value is that determined in the usual commercial testing and used in design calculations. Harder steels and most non-ferrous alloys show no y.p., but only a progressive slight deviation from the straight line portion of the stress-strain curve along which Hooke's Law holds. With these alloys, the "y.p.", when specified, refers only to some quite arbitrary total deformation, the amount depending upon the estimation of the observer. It is then more satisfactory to apply a proof stress (q.v.), to obtain a value which can be used in design. *See also Load-Extension and Stress-Strain Diagram.*

"Yield Stress" (Dalby). The static stress, developed by a material, which first causes a visible permanent set. It will be noted that this s. is not necessarily the same as the s. at the y. point; which, however, is sometimes termed, colloquially, the y.s.

Young's Modulus. The ratio, within the elastic limit of the material in tension, of stress to corresponding strain. It is the stress, usually returned in lb. per sq. in., which would cause, in a standard test piece, an extension equal to the original gauge length, if the material were capable of elastic extension to such a degree. Of course the material is not elastically so extensible, and a more reasonable way of expressing this constant is that it is 1000 times the stress which would cause an elastic extension equal to $\frac{1}{1000}$ th of the original gauge length. Y.M. is of the order of magnitude of 30,000,000 lb. per sq. in. for all steels; and considerably less for most other alloys. *See also Elastic Modulus.*

Z

Zinc. Zn. El. A.W. 65.38; At. No. 30; S.G. 7.1; M. Pt. 419.4° C. Bluish-white metal, comparatively hard and brittle at ordinary temperatures but ductile at 100°–150° C., when it can be drawn into wire and rolled into sheet; shows excellent resistance to atmospheric corrosion. Occurs as *calamine* or *zinc spar*, ZnCO_3 ; *zinc blende* or *black jack*, ZnS ; *franklinite*, $\text{ZnO} \cdot \text{Fe}_2\text{O}_3$; *willemite*, $2\text{ZnO} \cdot \text{SiO}_2$, and other minerals. Extracted usually by roasting the sulphide to oxide, which is reduced in fireclay retorts with powdered coal, the zinc being distilled off. Commercial z. is known as *spelter* (q.v.), which can often be used without refining. It is purified by gravity concentration in a reverberatory furnace, in which most of the lead, because of its greater density, separates at the bottom of the melt, while a zinc-iron alloy (hard zinc) separates between the lead and the zinc, these layers being variously separated. Used in hot-dip galvanizing and sherardizing (q.v.) as a rust-proofing coating on iron and steel, while z. sheet is being increasingly employed for a similar purpose. Z.-base die-castings have a great variety of uses. Z. is also an essential constituent of brass, bronze, manganese bronze and nickel silver; and is also used in aluminium, magnesium and other alloys.

Zirconium. Zr. El. A.W. 91.22; At. No. 40; S.G. 6.53; M. Pt. 1927° C. Silvery-white very hard strong metal, very resistant to atmospheric corrosion; but chemically very reactive, with a low ignition temperature and a large heat of combustion. When prepared by the thermal decomposition of z. tetra-iodide by a special process, can be produced in a ductile state and formed into wire and sheet, having a high resistance to corrosion. Occurs as *zircon*, ZrSiO_4 , and other minerals. Extracted from the oxide by reduction with calcium, aluminium or magnesium; or by the electrolysis of potassium z. fluoride in a melt of sodium and potassium chlorides at temperatures between 600° and 800° C., using a molybdenum strip as the cathode. Used in a finely divided state as a smokeless flashlight powder and a primer for ammunition. Both the powder and ductile metal are excellent gas "getters" and are widely used in many types of radio tubes. Z. is also used for rayon spinnerets, electric lamp filaments; and, as ferro-z., as a scavenger in steel casting. Z.-nickel steels are used for armour plate; and z., with nickel or cobalt and molybdenum or tungsten, has also been successfully employed as a constituent of high-speed steels and cutlery. Z.-columbium-tantalum alloys are used as a substitute for

Zir

platinum for non-corrodible chemical apparatus. Z.-nickel-silicon-iron alloys containing 2·7 per cent. of z. are used in the U.S.A. as materials resistant to hydrochloric and sulphuric acids. A copper alloy containing 14-16 per cent. of z. competes with the copper-beryllium alloys.

